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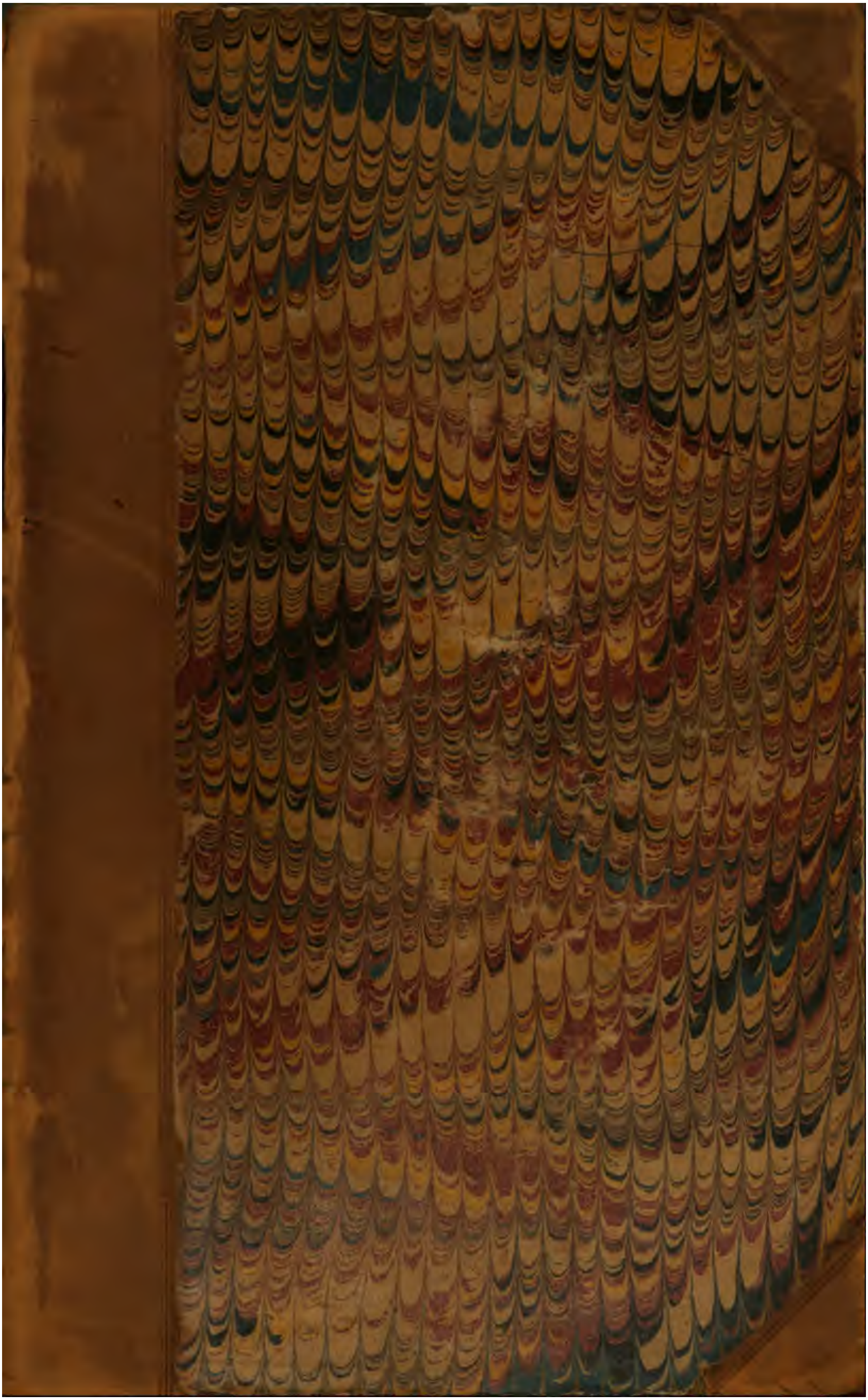

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Phys 2371

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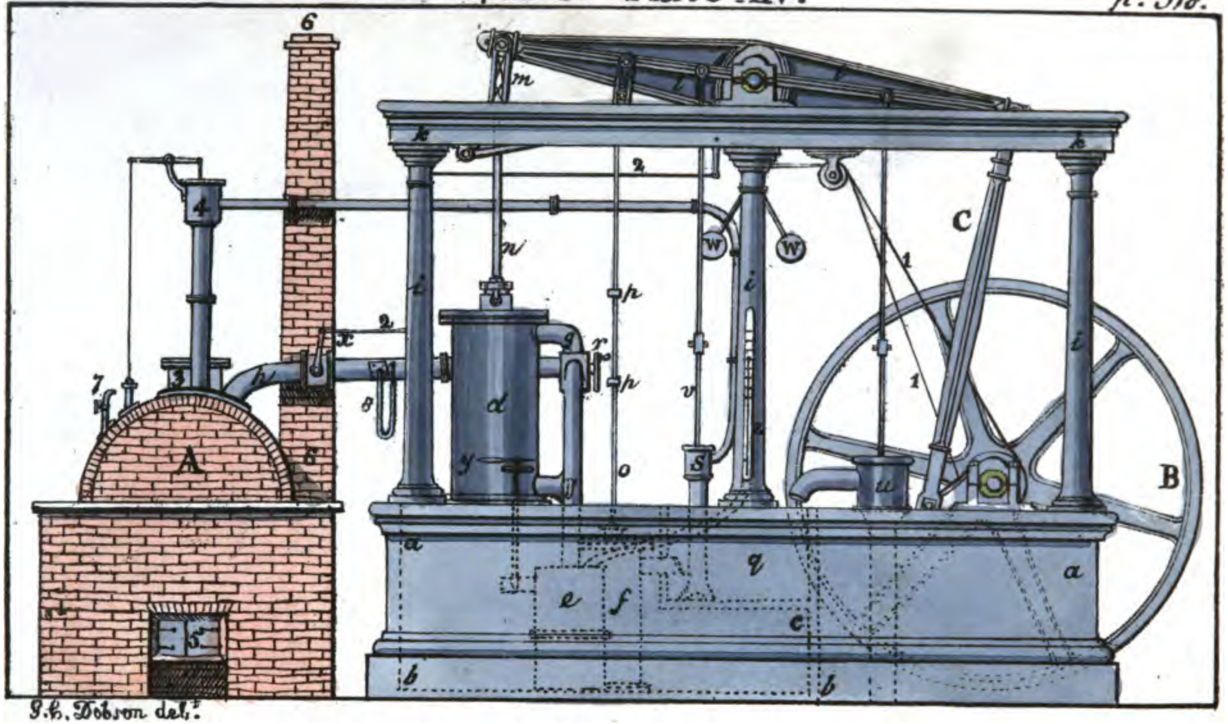

J. C. Dobson del^t.

AN

EPITOME

OF THE

ELEMENTARY PRINCIPLES

OF

NATURAL AND EXPERIMENTAL PHILOSOPHY.

PART THE FIRST.

COMPREHENDING THE GENERAL

PROPERTIES OF MATTER,
MECHANICS,
PNEUMATICS,
ACOUSTICS,
HYDROSTATICS,
HYDRAULICS.

AND A COPIOUS ACCOUNT OF
THE INVENTION, PROGRESS, AND PRESENT STATE OF

THE STEAM ENGINE;

BEING THE SUBSTANCE OF
A COURSE OF LECTURES ON THESE SUBJECTS,
DELIVERED AT THE ROYAL AND LONDON INSTITUTIONS, AND AT GUY'S HOSPITAL, SOUTHWARK,

BY JOHN MILLINGTON,

Civil Engineer, County Surveyor to Bedfordshire, Professor of Mechanics in the Royal Institution of Great Britain, Secretary to the Astronomical Society of London, Honorary Member of the Bath and West of England Society, M. G. S. &c.

With an Index
AND FOURTEEN LITHOGRAPHIC PLATES.

The Second Part, when published, will comprehend the Sciences of Magnetism, Electricity, Optics, and Astronomy.

London:
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1823.

Phys 237.1

PREFACE.

THOSE who look into the following sheets must not be disappointed at finding they do not contain a complete Treatise on all the various sciences of which they profess to treat, following them through their several trains of analytical reasoning. Far humbler are the Author's pretensions, for this little work is merely the essential parts of a popular Course of Lectures on the Mechanical properties of ponderable matter, which he has had the honor of delivering several times before the Members of, and Subscribers to, the Royal and Surry Institutions, and in the Theatre of Guy's Hospital, Southwark; to which he has likewise added, the leading features of a distinct Course upon the Steam Engine, as read at the former establishment in the winter of 1819, and afterwards partially repeated, among other Lectures, at the London Institution; and he is proud of this opportunity of publicly expressing his gratitude for the very flattering marks of approbation which his humble efforts met with at these highly useful Establishments.

To his Auditors and Pupils the present volume is therefore, more particularly addressed, the more especially as it was undertaken at the request of some of them, who wished to possess a more faithful outline of the Lectures read before them, than they could obtain by taking notes or depending on the assistance of their memories. At the same time he cannot help hoping, that the matter contained in it, will be found generally interesting to the public; on which account he has been careful to so arrange it, that while it may serve as a text book to his Lectures, it may also be read with advantage without them. The foregoing is the best and only apology he can offer for adding one more, to the already very extended catalogue of elementary books on science, many of which are so excellent that few could be found possessing sufficient arrogance to attempt their improvement. He does not, therefore, ground his claims to public favor on any pretended improvement or novelty of arrangement, but on the circumstance of his Professional duties as a Civil Engineer having compelled him, through the greater part of his life, to be constantly making practical application of Philosophical principles on a large scale. He trusts, therefore, that if no new light is thrown upon the subjects themselves, still that many more practical examples and hints will be found interspersed in this, than in many other similar or even more extended works on the same subjects. His principal aim has been to produce a book which might be useful both to the Gentleman and practical mechanic, by giving a general insight into the laws and operations of nature, without entering into their minutiæ, or the demonstrations by which they are analytically proved, and by offering simple, though in some cases merely approximate rules, by which the powers of machinery, and the operations of some of the agents of nature may be determined.

His original intention was to have confined himself to a mere enumeration of the principal facts, demonstrations, and experiments, adduced in his usual course of Lectures on Natural Philosophy, without attempting the description of the instruments or means by which they were proved or performed; from an idea, that as these were exhibited and orally explained, such a repetition might prove irksome to the student. With this determination the first sheets were sent to press, which will account for the brevity of the first, and part of the second section. Such an arrangement would have rendered the work nearly useless to those who had not previously been his Auditors, and he therefore afterwards altered his plan to one of a more extended nature, hoping thereby that if his labours should be found at all beneficial, they might prove equally so to those who were distant, as well as to those immediately around him.

The arrangement of the subjects is that which appeared the most natural, namely, to begin by considering solid matter as at rest, and in a primitive or simple state; then to examine it under the influence of attraction and motion, and afterwards in the states of fluidity and vapour. These heads comprehend all that is known of ponderable matter, and with them the present part of the work terminates.

The second part, which is intended to treat of imponderable matter (if such a term can be applied to it), or Magnetism, Electricity, and Light, has little or no connection with the first subjects, and therefore forms a very natural division of them, and such a one as will render both the volumes completely distinct from each other. Considerable progress has, however, been made in the second part, and it is intended that it shall appear as speedily as possible. To this a concise account of the Science of Astronomy will be added. This may appear a deviation from the arrangement, because, in strict propriety, Astronomy should follow immediately after Mechanics, as being dependant for its explanations on that branch of science. Still, however, as the objects of its research are distant, and not tangible, the effects observable in them can only be duly explained by reference to Optical as well as Mechanical principles; and as vision is influenced by the atmosphere that surrounds us, so the correct perception of astronomical effects requires a greater store of knowledge than is necessary for any other science, which it is hoped will prove a sufficient apology for removing it out of its natural order of arrangement.

The account of the Steam Engine, with which the present volume closes, is much more extended than was originally intended; upwards of 116 pages, and five of the plates, having been devoted to it; but for this it is hoped no apology will be deemed necessary. No work on experimental Philosophy can be complete without a mention of this important machine; and the Author's practical and intimate acquaintance with it for many years, added to the very little that has been written upon it in small works, induced him to make this extension, from a conviction that every Englishman must feel a desire to become acquainted with that machine which has contributed so largely to the perfection of the manufactures of his country. Indeed, it cannot but be matter of surprise, that, among the immense number of volumes annually issuing from the British press, no detached works on the Steam Engine have ever appeared in our language, since Savery's Miner's Friend, except Curr's

Coal-viewer in 1797, now obsolete, on account of the alterations and improvements in the machine, and the work of Mr. Partington, of the London Institution, which was presented to the public at the close of the last year.

At the time of commencing this work, the art of Lithography, or printing from stone, was much less known than at present, and he was therefore induced to have his plates executed in this manner, thinking that specimens of so new and curious an art would be interesting. The Plates cannot boast of elegance; but as they have been done under his immediate inspection, he knows that they convey correct ideas of what they are meant to represent, and trusts they will answer every purpose of explanation. He has only further to lament, that, small as the present work may appear, he has been unable from his many professional engagements to give his whole and undivided attention to it. It has therefore, necessarily, been written and printed at different times, and in detached parts, whenever he could snatch a leisure hour to devote to it, and oftentimes when absent from home. This is the only apology he can offer for many errors, repetitions, and inaccuracies, that have crept into it; some of which he has endeavoured to correct by the table of Errata, and for such as remain, he must throw himself upon the kindness of his readers for excuse.

6, Leigh Street, Burton Crescent,
London, 18th February 1823.

ERRATA.

Page 8—Line fifteen from top, *for* increase *read* decrease
13—Add the article a, to the end of the third line from bottom
15—Third line from top, *for* where *read* when
28—End of third line from top, *for* F *b* &c. *read* E *b* &c.
33—End of line fifteen from bottom, *for* 7 inches *read* 6.8 inches
35—End of line seventeen from bottom, *for* one *read* the
46—Line eleven from bottom, *for* at an *read* in an
63—Line sixteen from top, *for* snips *read* ships
Line ten from bottom, *for* suen *read* such
64—Line two from bottom, *for* o power *read* of power
66—Last line, *for* consequent *read* consequently
69—Sixth line from top, *for* equa *read* equal
77—Fifth line from bottom, *after* screw *add the word* is
79—Seventeenth line from top, *for* thread *read* threads
85—Fourteenth line from bottom, *for* atio *read* ratio
91—Third line from top, *for* pessure *read* pressure
100—Twentieth line from top, *for* between w *read* between n
101—Third line from bottom, *before* 14 *insert the word* nearly
108—Fourteenth line from top, *for* where *read* when
110—Sixteenth line from top, *for* water *read* air
117—Fifth line from top, *for* value *read* valve
128—Fifth line from bottom, *for* f that *read* of that
133—Last line, *add the word* when *before* a wild
135—Last line, *for* d'Lambert *read* D'Alembert
165—Last line, *for* members *read* numbers
167—Fourteenth line from bottom, *for* mark *read* marked
188—Fourth line from bottom, *invert the* comma *before* lateral
190—Eleventh line from top, *for* tilling *read* tilting
191—Sixth line from top, *for* shows *read* shew
Thirteenth line from bottom, *insert* a semicolon *after* escaping
211—Thirteenth line from top, *for* weight *read* weighs
221—Second line from bottom, *for* then *read* there
Fourth line from bottom, *for* descend *read* ascend
222—Fifth line from bottom, *for* flat *read* float
227—Fifteenth line from top, *for* wate *read* water
Last line, *after* fall *add* is
231—Third line from bottom, *for* experimenta *read* experimental
247—Eleventh line from bottom, *for* prineiples *read* principles
249—Fourth line from top, *for* in the table *read* to the table
250—Thirteenth line from bottom, *for* sitnation *read* situation
285—Eighteenth line from bottom, *for f read d*
299—Fourth line from bottom, *for* their *read* its
302—Ninth line from top, last word, *for* or *read* of
307—Fourteenth line from bottom, *dele* rod
313—Last line, *for* 666 *read* 283
316—Eleventh line from top, *for* picton *read* piston.

AN EPITOME, &c.

SECTION 1.*

AT an enlightened period like the present, when Philosophical Researches are pursued with avidity, and generally cultivated, any comment on their utility, it is presumed, must be unnecessary in a publication like the present, which does not profess to be a Treatise, or even an Essay, on the various Branches of Physical Science, of which it treats, but merely as its title expresses, An Epitome or Abridgement of a Course of Lectures on the Mechanical and Mathematical Branches of Natural Philosophy, published for the purpose of assisting the memory of the Student, in the most material and essential points which ought to be recollected. The advantages which oral instruction has, when aided by demonstration and experiment, (as is the case in lectures) over that which is obtained by reading, is also sufficiently evident; for it is universally found that an explained experiment will, by its simplicity, make a much deeper impression on the mind than the most elaborate description.

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* The subjects of this work are divided into Sections in preference to Lectures; for as the quantity of information conveyed in a Lecture must depend upon its length, which is often various, so it was found more convenient to adopt this arrangement; but as the order is preserved the Student will find no difficulty in following the subjects.

With a view, therefore, of impressing these Lectures more strongly on the mind, the present little work has been composed; in which it is intended to give, not only an outline of each Lecture, but to convey a clear idea of the manner of performing the several experiments brought forward to illustrate the same.

Experiment is now considered as the foundation of Philosophy, and nothing is admitted within its pale which will not stand its test. The philosophy of the moderns, in this respect, differs widely from that of the ancients, the one being built on the solid basis of reason and experience, while the other had nothing but vague conjecture for its support. That luminary of science, Lord Bacon, who was Chancellor to King James I. may be considered as the father of English philosophers. He was the first who stepped forward to rescue Science from the oblivion in which it had hitherto been obscured; and his endeavours being fortunately followed up by the learned Mr. Boyle, and the immortal Sir Isaac Newton, together with the foundation and establishment of the Royal Society, and the subsequent aid which philosophy has received from the labours and researches of the learned and ingenious, has been the means of exalting science to a degree of perfection which, in so short a time, could scarcely be expected by its fondest admirer.

In order to understand the various operations of Nature, it will be found necessary in the first place, to examine her in her most simple and unshackled state. We must endeavour to discover her primitive principles, before we proceed to the consideration of those which are compounded. The first Lecture is therefore confined to an examination of the *Nature* and *Mechanical Properties* of *Matter* or simple substance.

By mechanical properties are meant, those which are obvious upon any of the mechanical operations of weighing, breaking, measuring, or the like, without any regard to the composition of the thing examined. Thus the general mechanical effects of water will be the same, whether it be taken from a river or a spring, and so of the various gasses or airs, although if their composition be examined, they will be found very different. Such an examination can only be effected by chemical means, and the properties so discovered may therefore be very properly called the *Chemical Properties of Matter.*

MATTER is the general name which has been given to every species of substance or thing which is capable of occupying space, or which has the qualities of length, breadth, and thickness, consequently, every thing which can be seen or felt is said to be Matter.

In describing the properties of matter, it must be understood, that they do not apply to the masses or substances commonly met with, but to the Uncompounded or Primitive Materials of which such substances are formed. These original component parts of which all substances are made up, are stiled simple matter, elementary principles, or simply *Elements.*

The Ancients suppoied there were but four Elements or simple substances, viz. Fire, Water, Earth, and Air; and that out of these, or certain combinations of them, all the substances in nature were formed; they have been handed down as the whole of the elements, but modern chemistry has discovered that these are not all simple, and in lieu of them, has introduced a catalogue of upwards of 40 ingredients, which, from their having resisted every attempt that has been made to decompose, or divide them, seem entitled to be called Elements. For the names and particulars of these the Reader must refer to any modern Chemical work.

Notwithstanding the various substances which nature offers to our observation may differ essentially in touch, weight, and appearance; yet the elements of which they are composed all possess the common mechanical properties of matter, which properties are five in number, namely, I. The particles of matter are solid, and occupy space. II. They are infinitely divisible. III. They are impenetrably hard. IV. They possess mobility, but are inert; and V. They universally attract, and are attracted.

The first of these properties needs no proof, for the definition already given of Matter is, that it has length, breadth, and thickness, and nothing can have these properties without occupying space, and being solid. These characters exist in all matter. although at first they may be invisible; thus air, which cannot be seen, is matter; for if a glass tube, open at both ends, have its upper end closed by the finger, while its lower one is immersed in a jar of water, it will be seen that the air is material and occupies its own space in the tube, for it will not permit the water to enter it, until the finger is removed, when the air will escape, and the water rise to the same level in the inside, as on the outside of the tube.

The second property of Matter is that it is infinitely divisible, or in other words, that the original component parts, or elementary particles of which all things are formed, are small beyond conception: thus, if marble, or any brittle substance, is reduced to the most impalpable powder which human art can produce, its original particles will not be bruised or affected; since if this powder be examined by a microscope, each grain will be found a solid stone, similar in appearance to the block from whence it was broken; and of course if we possessed suitable implements, would admit of being again subdivided or reduced to a still finer powder. If a single grain of copper is dissolved in about fifty drops of nitric acid, and the solution is afterwards diluted with about an ounce of water, it is evident that a single drop of it must contain an almost immeasurably small portion of copper, and yet so soon as this comes in contact with a piece of polished steel or iron, that metal will become covered with a perfect coat of copper, consequently, as much iron may be covered with copper as the solution will wet, which shows how infinitely the copper can be divided without any alteration in its texture.

Gold is so extended under the hammer of the workman, in forming it into the thin sheets called leaf gold, that the 500,000th part of a grain becomes visible to the naked eye, or the 50,000,000th part, through a microscope, magnifying but ten times: and Mr. Ferguson has calculated that a single pound of gold would be sufficient to cover a silver wire capable of encompassing the earth, or about 24,000 miles in length! But the wonders of art sink into nothing, when compared to those which nature produces; for Mr. Leewenhock, the celebrated microscopic observer, affirms, that he has counted two millions of animalculæ in a portion of the milt of a cod fish not longer than a common grain of sand!! That Matter is thus infinitively divisible also admits of demonstration on mathematical principles.

Nature seems to have adopted the Third Property of Matter, viz. its impenetrable hardness, that her works might be everlasting, and incapable of wearing out; for although matter, in many instances, seems to disappear, as in the cases of burning and evaporation, yet the Chemists's art distinctly proves, that it is incapable of annihilation, and that the original particles, in all cases, still exist, though by change of arrangement they are made to assume a different appearance. Even substances which appear soft, such as air and water, appear hard when submitted to proper examination, for although the constituent particles cannot be experimented upon, yet the effect of their aggregation may be shewn in several ways: Thus, a quantity of water falling in an open tube appears to exert no particular force, on account of the resistance it meets with from the air; but if that air is previously removed by ex haustion there will be no resistance, and the water will sound like the falling of shot or stones instead of water. Such an instrument is called a Water Hammer. The hardness and incompressibility of water, is also admirably proved in the action of Bramah's Hydraulic Press—(for a description of which see Section on Hydrostatics.) Air differs from water in being elastic, but its solidity is shewn by the difficulty of compressing a bladder filled with it, and by the loud report which is produced by a column of it, bursting a bladder, tied over the top of an exhausted receiver.

The Fourth Property of Matter, that it possesses mobility, but is inert, is the constant object of our observation. By its mobility is, meant, that it always may be moved, if a sufficient force is applied to overcome its weight or vis inertiæ; and by being inert we are to understand that it is inactive, or indifferent to either rest or motion, and admits of either, but always exerts a power to remain in that state in which it is found. For instance, when a person is riding on horseback, and the horse suddenly stops; or in a carriage, or boat, which is impeded by striking against an obstacle; the person is thrown forwards, from his insensible endeavour to remain in the state of motion, in which he then was; and that this is the case with inanimate, as well as animate, nature will appear by giving a sudden push to a bowl of water, when the water will flow over on the side on which the impulse is given; but if once the bowl is put into motion, and then suddenly stopped, it will flow over on the opposite side. Numberless other instances may be found in the difficulty of putting heavy bodies, such as ships, loaded waggons, &c. into motion. From this Property of Matter, if a stone, or any inanimate mass, is undisturbed it will remain for ever motionless; and when once put into motion, would continue in it, and move for ever, were it not for some resistance. A bowl stops on the bowling-green through the resistance and friction of the grass and the air, and there is no doubt, but if it moved on a polished surface it would proceed much further; but even in that case the air, on account of its solidity, would afford some resistance, and in time stop it; while if it moved in a space devoid of air, as in the vacuum of an air pump, and met with no resistance from the plane on which it was moving, it would continue to move for ever, because the only obstacles to its motion are supposed to be removed. Such is the case with the Moon and Planets, for these move in infinite space, unchecked by friction or resistance, and therefore always keep up that motive force which was communicated to them by their Great Maker at the creation. The Subject of Planetary Motion will be more fully considered when speaking of Astronomy.

Attraction is the Fifth Property of Matter, and exists in every individual particle. All matter attracts and is attracted in proportion to its quantity, therefore all things upon the earth incline or are drawn towards its centre, because the earth is the largest mass of matter in their immediate vicinity; for the same reason a two-pound weight is twice as heavy as a one-pound, because containing twice the number of particles, it is twice as strongly attracted, for weight is nothing more than the resisted effect of the earth's attraction. There are several kinds of attraction distinguished by the names of Cohesion, Gravitation, Magnetism, Electricity, and Elective Attraction or Affinity. These, in their general effects, with the exception of the last, appear nearly similar, although they depend upon different circumstances. The attractions of Electricity and Magnetism are explained in the Lectures on those Subjects.

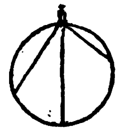
The attraction of Cohesion is that power which unites the separate or individual particles of matter, and forms them into masses or bodies. This attraction in general does not extend to any sensible distance from the body, and hence, when the parts of any substance are separated or broken it is difficult to unite them, but if they can be brought into sufficiently close contact this attraction operates, and they are joined. On this principle, two pieces of hot iron may be hammered together and joined: a plate of lead and one of tin, passed together through a flatting mill, become united into one plate of metal. Glues, cements, and solders, act upon the respective substances to which they are applied in the same manner, by stopping up the pores or interstices, and and making the contact more perfect. The agency of this principle is shewn by pressing two lead planes together, when they will adhere with such violence as to require considerable force to separate them: and the increasing ratio of this attraction, as bodies approach each other, is very well shewn, by floating two equal sized cork balls on the surface of water, when they will run together with an accelerated motion, the force increasing as the squares of the distance increase. The power which holds all things to the earth's surface is this same attraction, but when spoken of as applying to worlds, it is called *Attraction of Gravitation.*

As the attraction of Cohesion is common to all matter, it would appear, that particles of every description should indiscriminately cohere, and stick together, and form substances, and consequently, that an infinite variety of compounds would be found in nature, with the almost impossibility of any two of them being alike; and such would undoubtedly be the case, were it not for that modification of attraction called Affinity, or Elective Attraction, which being more properly a Chemical than a Mechanical Property of Matter, will not be discussed in these Lectures. By this, however, the general effects of Cohesion are restrained, and only one particular species of matter will unite with another, unless in some cases by the interposition of a third or fourth material, in consequence of which, only a definite number of natural substances are formed, and the same thing always appears with nearly similar characters.

Capillary Attraction is that species of attraction by which fluids are raised in small tubes, and is a modification of the Attraction of Cohesion. If a capillary tube be immersed in a fluid, that fluid will rise to a certain height in it, proportionate to the size of its bore, rising higher the more the tube is diminished. This depends upon the cohesive attraction exerted by the sides of the tube, and accounts for sap rising in the pores or tubes of vegetables. The increasing force of this attraction, with the diminished size of the tube, is beautifully shewn by two square glass planes touching at one edge, and separated at the opposite one by a wedge; on immersing these in water, and then raising them out of it, a portion of the water will be retained in that curve which is called an Hyperbola. Here we perceive, that as the distance of the glass planes increase in arithmetical proportion, their power of attraction decreases in a geometrical ratio. Capillary attraction also causes fluids to rise in sponges, sugar, sand, and other porous bodies as soon as they come into contact with them.

The density of bodies, by which is meant their variation in weight while of the same dimensions, most probably depends upon their original moleculæ or particles being of such forms, and so disposed as to admit of their coming into more or less close contact; thus a greater number of particles will pack or lay in any given space, if their forms are regular, than could do so, if they were irregular and could not touch each other. For example, if it be supposed that a million particles of gold are contained in a cubic inch of that metal, 500,000 particles of iron, might also be capable of occupying that same space, or 100,000 particles of wood. In the iron and wood there must therefore be many more pores or interstices than in the gold, and of course the gold will be the heaviest or most dense: this increased density and weight does not therefore arise from the individual particles of gold being heavier than those of wood, but from a greater number of them being forced into the same space, for the original particles of matter are all presumed to be of the same weight, and thus gold, which is one of the heaviest solids will, when dissolved, remain suspended in ether which is the lightest of all visible fluids. It is impossible to obtain the absolute weight of bodies, which vary in density, by weighing them in the open air, for the air will buoy up that which has the least density, more than that which has the greatest; and thus, although a piece of cork and one of lead may exactly balance each other at the ends of a scale beam, yet that balance will be destroyed so soon as they are placed in an exhausted receiver, for then the cork, by loosing the buoyant assistance of the air, will preponderate, thereby proving that it contains more matter than the lead, though not in the same compass. This effect is sometimes further elucidated by the experiment of letting a guinea and a feather fall together in a tall glass receiver; when this is full of air, the guinea falls while the feather is floating about, but when the air is withdrawn from the receiver, they both reach the bottom at the same instant.

Since the earth is of a globular form, and the power of attraction is in proportion to the quantity of matter, so of course the inhabitants, and all things upon the earth's surface, will be attracted, or drawn downwards, in a direction tending to its centre, for since the longest line, which can be drawn through a circle or globe, is a diameter, which must pass through its center, so this will likewise pass through the greatest quantity of matter contained in any one direction in it, as will be seen in the annexed figure, and consequently, all bodies will fall in a direction pointing to the center of the earth. Hence the use of plumb lines, for obtaining perpendiculars to the horizon, or earth's surface at any point; for setting the the sides of buildings upright, &c.



Notwithstanding the above five properties are those which are generally ascribed to matter, yet it possesses another of great importance, viz. its power of arrangement, commonly called *Polarity*. The attraction of cohesion sufficiently accounts for the formation of masses or substances, by drawing the original particles of matter together, and then holding them; but it is found that they are not only drawn and held together, but that the same matter always takes the same arrangement or formation. Thus a piece of iron, tin, or any other metal or substance, will, when broken, always exhibit the same arrangement and disposition of parts, or *Grain*, as it is generally called: and so strictly are the laws of combination found to prevail in the union of elements and formation of substances, that a most valuable, new, and important character is given to modern chemical researches, approaching almost to mathematical precision; it being not only ascertained, that the same materials will in most cases assume the same form, but that the ingredients which enter into the formation of substances, do so in certain definite proportions which cannot be changed without also changing the character of the substance they form. This is unquestionably a mechanical or mathematical examination of matter, but it is of so much more utility and importance in a chemical, than in a mechanical point of view, that it becomes unnecessary to dwell upon it in this place.

SECTION II.

MECHANICS.

MECHANICS is a science which has for its object the nature of Weight and Motion, and the means by which they are produced, as well as the laws by which they are regulated. It applies to every species of Matter, but as the action and effects which are met with in solids and fluids differ very materially, the latter are generally considered under the distinct name of Hydro-dynamics, while Mechanics is more generally confined to the examination of the weight and motion of solids. As some fluids are elastic, while others do not possess this character, so Hydro-dynamics is likewise subdivided into two branches, the first of which is called Pneumatics, which considers the Mechanical Properties of Air, and all fluids which are of an elastic or springy nature, while the other, called Hydrostatics, examines water and all other fluids which possess little or no elasticity.

The science of Mechanics arises naturally out of the properties of matter, as detailed in the first Section, and is in fact but an extended considertion of them. For attraction is not only capable of uniting the particles of matter, so as to form them into substances, but by extending beyond their limits of producing weight and motion; for the weight of bodies is nothing more than the effect of their attraction towards the earth, being resisted. Since all matter attracts, and is attracted, with a force proportionate to its quantity, it follows of course that the earth, or globe which we inhabit, being the largest mass of matter in our immediate vicinity, will attract all things upon, or near its surface, towards itself, and in a direction tending to its center, for a reason which has been before explained,(page 10), and of course they will fall towards the earth; but if they are supported, and prevented from approaching it, either by the hand or any other means, the tendency to approach the earth will be felt, and is called *Weight*, for weight is nothing more than the resisted attraction of the earth, and as this attraction is always in proportion to the quantity of matter, so of course a large body will be more powerfully attracted, or in other words, will be *heavier* than a small one. This attractive influence is not confined to the earth alone, but exists in the sun and all the planets, which exert their attraction upon each other, and in this case it is called *Gravitation,* to distinguish it from Cohesion, which latter term is only applied to bodies that are very close, or in immediate contact with each other.

Notwithstanding the similarity which thus seems to exist between Gravitation and Weight, they must not be confounded, the first being the cause, while the latter is the effect.

Since the weight or gravitating effect of all bodies is dependant upon their quantity of matter, without any reference to their size or dimensions, it follows that it must be influenced by their *Density*. This term is used to express the relative quantities of actual matter, which bodies contain in respect to their bulk, for the original particles of all matter are believed to be of the same weight. A cubic inch of gold is, however, heavier than one of lead, and that again is heavier than one of wood, although they are all of the same size; but this does not arise from the individual particles of either of these substances being heavier than the others, but from greater number of particles being packed or compressed into the same space; thus there are many more original particles in the cubic inch of gold, than there are in that of lead or wood, consequently such particles must be in a state of more compact or close arrangement, and that body which contains the most is said to be the most dense. In proof of this assertion, the density of bodies may be changed without affecting their weight, but in this case their bulk must always be increased or diminished, inasmuch as the particles themselves are not augmented or diminished, but are set at a greater or less distance from each other; thus suppose that a quart of air, in the ordinary state of the atmosphere, weight 16 grains, this same quantity of air may, by means of the air pump, be made to expand itself so as to fill four quarts, and still it will weigh no more than at first, although its bulk is four times increased, and consequently, its density four times diminished. Caloric, or the matter of heat, has the property of increasing the bulk of all bodies, by setting their particles at a greater distance from each other, but it adds nothing to their weight, consequently, all bodies while hot will be less dense than when cold, as may be proved by weighing the metalic bar of a pyrometer when hot and cold, when no difference will be found, although the instrument clearly indicates, that such bar becomes longer, and of course thicker, by being heated. The use of the pyrometer is to ascertain the quantity of expansion that takes place in solid bodies, with certain degrees of temperature. An inquiry of the utmost importance in clock and watch-making, and many other processes, as will hereafter appear when the *Pendulum* is spoken of.

It is impossible to prove that the original particles of matter are of the same weight. The experiment of dropping a guinea and a feather at the same instant from the top of a tall glass receiver, previously exhausted or emptied of its air by means of the air pump, is sometimes used for this purpose; but is by no means satisfactory when made with this view. Perhaps the most decided proof of the equality of the weight of the original particles is that which has been before mentioned, of dissolving gold in nitro-muriatic acid, and transferring it to ether, where it will not settle, but will remain equally suspended in every part of the fluid.

As Weight arises out of the Fifth Property of Matter, so *Motion* is dependent upon the Fourth, which premises that matter is mobile, or can be moved, but inert or passive, or indifferent to either rest or motion, endeavouring to remain in the state in which it last was. Since, therefore, matter is incapable of moving itself, all motion presumes the existence of some force sufficient to produce it, which may be either gravitation, animal strength, or the exertion of elasticity, as in springs, the steam engine, &c. The cause of motion, whatever it may be, is in Mechanics called the *Power*, and that which it has to overcome, the *Resistance.*

Motion becomes apparent to our senses only by a comparison of the situation of bodies with regard to each other; on this account it has been contended, that if one body only had existence, motion must be unknown, because there would be no second thing with which its change of situation could be compared; and whenever the object of comparison is at all equivocal, it becomes very difficult to identify motion. Thus the motion of the earth is deduced from the fixed stars, objects that cannot be touched or examined, and from the great regularity of that motion it becomes impossible for an inhabitant to say whether he is in motion with the earth or stationary, while the stars revolve round him, though the science of Astronomy clearly determines the former to be the case. A similar difficulty arises as to the appearance of trees and houses being in motion when they are passed in a boat or carriage, but as these can be examined, our reason teaches us to know they are at rest, notwithstanding their appearance of motion.

Motion is said to be absolute or relative, according to the circumstances under which it occurs; absolute motion being a real change of place, while relative motion is but an apparent one. Thus a man walking from one end of a barge to the other, while that barge is stationary, is in absolute motion, because he not only changes his place with regard to situation in the barge, but to the earth under it, at the same time; but on the contrary, if he had walked from the head to the stern of the barge while it was proceeding with a velocity equal to his own, then he would have been in relative motion only, because although he would have changed his situation in the barge he would constantly have been over the same point upon the earth, and therefore in respect to it, would not have moved at all.

The Laws of Motion are I. That every Body will continue in a state of rest, until put into motion by some force applied, and if that force be single, the motion produced will be rectilineal, and will continue so, as long as it is produced by that force alone. II. Change of Motion is always proportional to the moving force impressed, and is always made in the direction of the right line in which the force acts. III. Action and Reaction are always equal in equal quantities of matter, and act in contrary directions to each other.

The first of these laws depends upon what is called the *vis inertiæ* of matter, by which is to be understood, not only that matter will not move itself without the application of some force, but also, that when once in motion it will endeavour to maintain that state.—Whenever therefore a body is put into motion, that motion would continue for ever in a right line, were it not stopped or impeded by some external force, such as the resistance of the Air, Friction, or the attraction of Gravitation, any of which will be capable of changing its direction, or in time stopping it entirely.

The Second Law teaches that any change, either in the direction or velocity of a body's motion, will always be in proportion to, and in the direction of the force that produces it. Thus if a body is moving in one direction, and is met by a new force, sufficiently strong to annihilate the former one, it will continue its motion in the direction of that new force; but if the old force be not annihilated, then since a body cannot move in two directions at once it will move under the compound force in a mean or diagonal direction, proportioned to the influence of the joint forces acting upon it.

The Third Law relates also to the vis inertiæ of matter, and teaches that the resistance of any body to enter into a state of motion is such as to cause it to react against another body producing that motion with a force proportionate to the velocity, and their respective quantities of matter.--This accounts for the recoil of fire-arms, and many other effects which are constantly met with.

Gravitation, or the attraction of the earth, is the only constant natural cause of simple motion that we, upon its surface, are acquainted with. This is always existing, and causes all things to fall in right lines towards the centre of the earth. All other forces, such as dispose bodies, to move horizontally, perpendicularly, or otherwise, are varying and casual, such as the force of wind, water, steam, gunpowder, or animal strength, and as these are exerted occasionally, while gravitation never ceases to act, so in many instances they form compound forces with it which will be afterwards considered.

The reason why this attraction acts in a direction tending to the earth's center has been explained before (see page 10), and the use of the plumb line then mentioned is derived from this principle; for as a plumb line consists merely of a string with a weight freely suspended at its lower end, so while the string prevents the weight from falling, it is at the same time stretched in the direction of a line pointing to the earth's centre, and thus gives the most correct perpendicular to the horizon that can be obtained, insomuch that it is not only used for the ordinary purposes of life, but for adjusting the best and largest astronomical instruments. From the circumstance of all plumb lines pointing to the centre of the earth, it is evident that no two of them (even at the smallest distance asunder) can hang in a direction parallel to each other; and Kepler thought this principle might be applied to the mensuration of the earth. It was attempted without success by Riccioli, an Italian astronomer, in a manner which will be explained in the first Lecture on Astronomy.

The same cause which urges a body to fall perpendicularly to the earth, also makes it roll or descend a hill; because it will be nearer to the centre of the earth at the bottom than at the top of that hill, and a true level plane, or one in which water will stand without flowing, must not therefore be a flat one, but one which is so curved as to be parallel to the earth's surface, or rather equi-distant at all points from its center, because if it were flat, it would be a tangent plane to the earth, and the point of contact C, Plate I. Fig. 1. being the nearest to the centre, the bal B, or any moveable matter, would run down, and could only remain at rest upon the point C, and not upon any part of the plane C B.

On this account the surface of the sea, lakes, or even small quantities of water or other fluids, are not flat, but partake of thc rotundity of the earth, every part of their surface being equi-distant from its centre.

The instruments by which horizontal lines are determined upon the earth are called levels; they are of various forms, but the best and simplest is formed of a truly cylindrical and straight tube of glass, hermetically sealed at both ends, but previously filled with water, or spirits of wine, so as merely to leave a small bubble of air as at Fig. 2. Plate I. When such a tube is held horizontally the bubble of air will remain stationary in the middle, as at A in the Figure, but as air is lighter than either spirits or water the bubble will always rise to the highest end, and consequently will only remain steadily in the middle when the tube is truly level. When a tube of this description is mounted in brass work, with sights to look through, or with a telescope, it is called a *Levelling Instrument.** The best levels have their tubes very carefully ground in the inside to insure their being perfectly straight, and are filled with ether, as being more sensible in its motions than any other fluid.

With a view to prove that it was the whole mass of the earth which produced the attraction of bodies towards it, and not any particular power in the centre alone, several experiments have been tried, but those of Dr. Halley, Mr. Cavendish, and Dr. Maskelyne, are the most celebrated; the first was tried in South America, and the latter upon the side of the mountain Schehallien in Scotland, when the plumb line was found to be drawn six seconds of a degree out of the perpendicular by the mountain's attraction. A body therefore placed in the centre of the earth, and free to move, would be motionless, for at the centre the attraction on all sides would be equal, and it must there remain suspended and fixed.

Bodies which fall in obedience to gravitation, will not only acquire such an additional momentum, or moving force, as will greatly increase their power, but will at the same time increase their velocity of motion, which will be continually accelerated. This arises out of the Fourth Property of Matter (page 6), and is so considerable that in descending but one inch and a quarter the weight or effective force of any body will be doubled. As the body proceeds in its descent, this effective force, or the force with which it would strike any resisting object, will increase as the square root of the distance it falls through, while that distance will increase in consequence of the acceleration or quickening of the motion, as the square of the time which is occupied in the descent, and thus the increasing force of a falling body, as well as the distance it will pass through in a given time may be calculated.

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* For the use and practical application of such Instruments, see Level, Rees's Cyclopedia; and Adams's Geometrical and Graphical Essays, 3d Edit. page 358.

Suppose for instance a brass ball weighing one ounce be taken, this will of course be balanced by an ounce weight at the opposite end of a scale beam, but if the ball be raised to the height of one inch and a quarter, and then permitted to fall upon the end of the beam, it will be found capable of raising two ounces, for by this distance of fall its effective force will be doubled. In order to again double this newly acquired force, it will not answer to raise the ball to double the former height of one inch and a quarter, because the momentum acquired by falling is not as the heighth of the fall, but as the square root of that height: consequently to produce a force of 2, or to double the last force, it must fall from 4 times the former height, or five inches, 4 being the square of 2. Again to triple the force the ball must descend from 9 times the height, or eleven inches and a quarter, and to quadruple it, the length of descent must be 4 times 4, or 16 times the original height of one inch and a quarter, and so on for any greater augmentation.

The force of gravitation is not equal over the whole surface of the earth, for reasons which will be explained in the Section on Astronomy; but about the latitude of London it is found by experience, that a body will fall 16 feet 9 hundredths, or about 16 feet and an inch, in a second of time, and consequently, as the space passed through is as the square of the time, at the end of the second second the body will be

4 times 16 feet and an inch, or 64 feet 4 inches, from its point of departure, at the end of the third second it will have advanced 9 times the first distance, or 144 feet 9 inches. From this it follows, that the increase of velocity in each succeeding second will be as the odd numbers, 1, 3, 5, 7, 9, 11, &c., because if the body passes through any one given space in the first second, it must pass through three such spaces in the second second, to produce the square number 4, which indicates the number of spaces it will have passed in two seconds, and again it will pass through five spaces in the third second, which added to the three in the second, and the one in the first, produces nine, the number of spaces passed through in three seconds, and so on.

This property of falling bodies, which equally applies to all such as are sufficiently heavy to prevent their being driven by the wind, is sometimes applied to the rough measurement of inaccessible depths, but it can only be relied on when the fall of the stone or other body is visible, as by dropping into water, for the noise made by the fall would deceive, without an intricate calculation, on account of the time which sound takes to travel.—(See Acoustics.) The rule, when the descent can be seen, is to multiply 16.09 by the square of the number of seconds between the starting and arrival of the falling body, but it needs no explanation to prove, that it must be a very vague and uncertain mode of proceeding, except in the hands of a very expert observer, since in great heights the fractional part of the latter seconds become of considerable importance.

The velocity with which a falling body descends is so great that the eye could not follow it, and consequently experiments could not be made upon the motion of such bodies with any certainty, did it not happen that the same effects take place when that motion is checked or diminished by a counterpoise, as when the body falls with its full and unrestrained velocity. Two weights may therefore be made so nearly equal to each other that when they are united by a long string passing over a pulley, the descent of the heaviest will be so slow that it can be distinctly observed, and thus the increase of the velocity according to the squares of the time may be accurately observed, particularly if a long paper scale of divisions, and a pendulum vibrating seconds, be placed behind the descending weight. Such an arrangement of apparatus was first invented and used by Mr. Attwood of Cambridge, and is (when well made) of great use to the Experimental Mechanic in determining the velocities and momenta of falling bodies under different circumstances. It is known by the name of Attwood's Apparatus.

A coincidence likewise exists between similar triangles inscribed in a larger one, and this increased velocity of motion; for if the perpendicular side of a right angled triangle* be divided into any given number of equal parts, as 1, 2, 3, 4, Fig. 3. Plate I. and these be supposed to represent equal portions of time, (seconds for instance), and then if lines be drawn from such points parallel to the base* and to the hypothenuse,* as well as to the perpendicular,* at their points of intersection, the large triangle will be filled with smaller ones similar in form to itself, although alternately reversed, and which, for distinction sake, are alternately shaded and white, when it will be seen that in the first period the space passed through by the falling body will be represented by one shaded triangle. The space passed in the second period will be represented by three triangles, viz. two shaded and one white, which added to the first makes four spaces: the third division contains five triangles, &c. &c.

Such will be the case when the simple power of gravitation is alone acting upon a moving body; but if a stone be thrown by the hand in a horizontal direction, it will be acted upon by two forces, *i. e.* by the muscular power of the hand which impels it forwards in a horizontal direction, while the power of gravity is constantly drawing it downwards towards the earth, and whenever a body is moving by virtue of two or more forces acting upon it at the same time but in different directions, or in other words, is under the influence of a compound, instead of a single or simple force, it will neither follow the direction of the one force or the other, but will move in a mean or diagonal proportioned to their respective powers; if the forces are continued uniformly that diagonal will be a right line, while on the contrary, if one or both of them vary, a curved direction of motion will ensue.

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* For explanations of these and other Mathematical Terms, see the Section on the Elementary Principles of Mathematics.

Thus if two continued forces are equal to each other, and are acting together at right angles upon a body *a* Fig. 4. Plate I. such forces may be represented by two straight lines of equal length *a b*, *a c* also forming a right angle, and in such case the body *a*, instead of moving toward *b* or *c*, will move in the direction of the straight lined diagonal *a d*, the length and situation of which will be determined by completing the square *a b d c*, by the dotted lines *b d*, *d c*, and drawing the diagonal *a d* from the angle *a* to the opposite one. But if instead of supposing the two forces equal, it is presumed that the force which impels the body *a* towards *c* is twice or thrice as powerful as that which urges it towards *b*, then the line *a c* must be twice or thrice as long as that from *a* to *b*, consequently the diagonal will no longer be that of a square, but of a parallelogram or oblong figure, as at Fig. 5, and so on for any other proportion of force.

If the forces are not uniform, but decrease or increase in the same proportion to each other, a similar effect will be produced; but should the one abate or increase more rapidly than the other, then the same diagonal motion will ensue, but it will be in a curved direction instead of being continued in a straight line. Thus in throwing a stone, or shooting a ball from a gun, the power of the arm, or of the gunpowder, will be continually diminishing from the resistance of the air, while the power of gravitation would remain equal were not its effects increased by the accelerated descent of the body, in the manner which has been already described, and the consequence is, that these two powers will in all cases so resolve into each other as to cause the projected body to describe a curve somewhat similar to *A Parabola.* Let *a* Fig. 6, represent a ball just discharged from a gun, then *a b* will represent the direction in which the force of gravitation will draw it downwards, and *a c* the direction in which the gunpowder impels it forwards, constituting two forces acting in opposition to each other, but from *a* to *c* it may be presumed the force of the gunpowder is so much greater than that of gravitation that the latter will not be felt, consequently the ball will proceed in a straight direction for a considerable distance. But the power of gravitation being constant, it may be presumed that at *c* the force of the gunpowder is so far spent as to permit it to begin its descent, and in doing this, if it falls through any given space *c d,* in passing on from *c* to *e,* it will perform the diagonal *c f,* and in the next equal space of time will descend through three times the distance *c d,* or from *f* to *g,* while the force of the powder will be so much more diminished as only to carry it as far as *h,* consequently it will be found at *i,* while in the next equal period it will descend through five equal spaces as at *k,* while it will only be projected forwards to *l,* and in the next period, as it must descend through seven such spaces, it will touch the ground at *m* and stop, having described a portion of a curve from the point *c* to *m,* or during all the time that the two forces were permitted to act upon it at once.

It may appear singular, but it is nevertheless true, that although the diagonal lines *a d* in Figs. 4 and 5, and *c f i l m* in Fig. 6, are much longer than the lines of descent *a b* in all these Figures, yet a projected body will describe this longer line in precisely the same time as it would fall simply from *a* to *b*. This arises from the velocity of motion being always proportionate to the force or power that produces it, and therefore in any of these Figures, 4 for example, where the forces are equal, if *a b* were acting upon *a* in the direction *a c*, instead of at right angles to it, it would cause *a* to move twice as far in the same time as the action of *a c* would do alone; but on the contrary, if *a b* were to act in direct opposition to *a c*, or in the direction *c a*, then *a* would not move at all, because the two equal forces would in this case neutralize and destroy each other, but being at right angles to each other they can neither have the power of doubling or destroying each other, but they do render that mutual assistance which causes the motion from *a* to *d* to be so increased in velocity, that the diagonal will be performed in the same time as would be necessary for the body to move along either of the sides, and of course the nearer the directions of the two motions are made to coincide, the longer must be the diagonal and the more rapid the motion, though it never can exceed that which would be produced by the union of the two forces in one line of direction. This will be rendered more evident by inspection of Fig. 7, where the lines representing the respective forces are kept of the same length as in Fig. 4, but instead of acting at right angles to each other they are made so far to coincide, that the diagonal becomes that of a rhomboid instead of a square, and is increased to nearly twice its former length, the same letters of reference being used in both cases.

The action of compound forces, and the motion produced by them, may be pleasingly illustrated by a little machine, consisting of two light frames of wood made to slide one over the other: one frame contains a perpendicular wire upon which a ball slides, and a string passes from the ball to the other frame, so that when the frames are moved, the motion of the frame constitutes one force, and the pulling of the string the other; and it will be found that while the ball passes from the bottom to the top of the one frame it will move over the diagonal of the other. This little instrument is shewn at Fig. 8.

There is one case in which a projectile body does not at first sight appear to move in the parabolic curve, and this is when a stone or other body is thrown up so perpendicularly that it falls upon the very spot from whence it was sent, but even then it must have performed a curve, otherwise as the earth is in rapid motion during its ascent and descent it would be left behind and could not fall upon the same spot; it is indeed this rapid motion of the earth combined with gravitation that constitutes the compound force acting upon the body, for while gravitation draws it to the centre, the earth's motion on its axis produces a centrifugal force at right angles to the first power, and thus a curvilinear motion must ensue.

The motion of the earth's surface, even in the latitude of London, is at the rate of 950 feet in a second, and as that motion is from the west towards the east, if a stone were projected to such an heighth as to take but one second for its ascent and descent, and this were to be performed in the same straight line, it must follow that when it fell upon the ground it would do so at the distance of 950 feet to the west of the spot from whence it was thrown. On account of the Fourth Property of Matter (page 6) such an effect cannot however take place, for the motion of the earth is communicated to the stone, in common with all other things upon its surface, and therefore if *a* Fig. 9 be supposed to represent the stone which is thrown up to *b*, in an apparently straight line, that line will not be straight, but like the curve *a b*, and as the same curve will be continued it will fall at *c*; now while the body is in the air describing the curve *a b c* the spot *a* upon the earth's surface will have moved on to *c*, and consequently the body will return to the spot from whence it was thrown, after having appeared to move in a straight line to an inhabitant of the earth, who, it must be recollected, is also in motion with the earth, and consequently the curve could only be apparent from a stationary situation detached from the earth, which does not exist; but the same thing may be rendered evident by a parallel case on a less scale, for if a ball be dropped from the top of the mast of a vessel under rapid sail, that ball will not fall into the sea behind the vessel, as might be suspected, but will arrive on the deck at the foot of the mast, having appeared to the inhabitants of the vessel to have fallen in a straight line, while the curvilinear direction will be apparent to a stationary observer on the shore, or in a contiguous vessel at rest.

When the forces acting upon a body, as in the two last cases, tend to draw it to a centre, and at the same time to make it fly off in a direction at right angles to the first force; such forces are called *Centripetal* and *Centrifugal*, and while they act in conjunction, and are a balance to each other, the motion which will ensue must be circular. Thus in Fig. 10, if S be supposed to represent the sun, and E the earth, the sun's attraction upon the earth will be a centripetal force represented by the line E *a* S, while the earth's centrifugal force or tendency to fly from the centre will be the line E C, and in consequence of these two forces the earth will move in the curved diagonal E *b e*, and will arrive at *e*; but in this situation an equal centripetal force S *d e* will exist, as well as an equal centrifugal force *e f*, in consequence of which the earth will be carried to *g*, and so on until it has performed the whole circle and arrives again at E, and as the forces in this and similar cases are not temporary, but permanent, of course the body E will continue to move in the circle F *b e g* for ever. The above may serve to convey a general idea of Planetary Motion, but must not be received as quite correct, on account of the interference of circumstances which cannot be explained in this place, and for an account of which the reader is referred to the Section on Planetary Motion under the head Astronomy.

That simple and useful instrument the Pendulum, by which alone we are enabled to obtain a correct mechanical division of time is dependent upon the laws of falling bodies, under the influence of two forces for its action. A simple rod or stick suspended by its upper end in such manner as to permit it to vibrate backwards and forwards, and with or without a weight at its lower extremity constitutes a pendulum, but in the general acceptation and use of this instrument the weight is employed; and the value of the Pendulum is derived from all its swings, vibrations, or oscillations, being performed in the same time so long as their distance or extent remains the same, and the length of the rod is not varied. From the above description it is evident that the motion of the pendulum weight will be in a portion of a circle. Thus in Fig. 11, if *h* be assumed as the point of suspension, *i* as the rod, and *k* be raised from its position of rest to *l*, it will immediately fall back again from *l* to *k*, and in doing this will acquire so much momentum that it will be incapable of stopping at *k*, but will proceed on to *m*, being very nearly as far to the right of the perpendicular line *h i k* as *l* was to the left of it. So soon as the momentum which carried it to *m* is exhausted, it will return again towards *l*, and so on, but with a force diminishing with each succeeding vibration until it again stops at *k*.

The pendulum therefore constitutes no part of the impelling machinery of a clock or watch, but is the mere measurer of time, and requires that the power of the weight or spring, by which the machine is made to move, should be communicated to itself in order that its vibrations may continue, and the means by which this communication is effected is called the *Escapement* of the clock or watch.

The vibrations of the pendulum are produced by its effort to fall, thus in Fig. 11, if the line *h i k* is perpendicular, and *n o* parallel, to the horizon, in raising the weight from *k* to *l*, it will in effect be raised the perpendicular height *l n*, and it will descend from *l* to *k*, performing the curved diagonal *l p k* in the same time, and with the same acceleration of motion, (see p. 25) as if it had fallen immediately from *l* to *n*; consequently if the pendulum is of great length so as to make the arc through which it vibrates approximate to a straight line, the distance *l n* will be so small that there will be but a very trifling difference in the length of time occupied by a long and short vibration, but in short pendulums this is of more importance, though seldom attended to in practice, for if the vibration be conceived to extend only from *p* to *q* instead of from *l* to *m*, then the descending power will be represented by the distance between the line *n o* and the points *p q* instead of by the distances *l n m o*.

The time which pendulums take to perform their vibrations is as the square root of their effective lengths without any regard to the amount of weight which may be appended to them; and this effective length is the distance between the point of Suspension, and another point called the Centre of Oscillation, or that point, in which, if all the matter of the pendulum were supposed to be collected, any force applied to it would generate the same angular velocity in a given time, as the same force, when applied at the centre of gravity.

The centre of oscillation can therefore only be determined by a calculation which takes into account the quantity and form of the weight, and of the rod by which it hangs; when that weight is a circular disc, such as is generally used for pendulums, and is very heavy in comparison with the rod, the centre of oscillation will be very little removed from the centre of the disc, but if a plane homogeneous rod or bar with parallel sides, or having the same dimensions from top to bottom be used, then the centre of oscillation will be removed upwards to two-thirds of the entire length of such rod or bar from its point of suspension.

The vibrations of pendulums being influenced by the motion of the earth, in a manner which will be noticed when treating of that motion, it becomes necessary that the length of those which are to perform their oscillations in equal times should be a little varied (see the manner of ascertaining the Figure of the Earth.) In the latitude of London, which is 51 degrees 32 minutes, it has long been considered that the length of a pendulum to vibrate seconds, or which would make 60 swings in a minute, should be 39 inches and 2-tenths. But through the late valuable investigations of Captain Kater, as detailed in the Philosophical Transactions, the length of such a pendulum at London is determined to be but 39.13829 inches, and since the time occupied by the vibration is as the square root of the length, so of course as a pendulum 39.13 inches, beats seconds, one to beat half seconds must not be half as long, but only 1-fourth of the length, or 9.7845 inches, and one to beat but once in two seconds must be four times as long as that for a second. Great attention must therefore be paid to the length of a pendulum when used for regulating the time of a clock, for although the difference may be imperceptible in a few vibrations, yet when it is recollected that the pendulum for seconds must make no less than 86400 to 30.

Fig. 1.

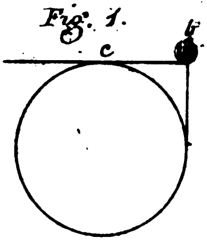


Fig. 2.

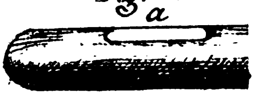
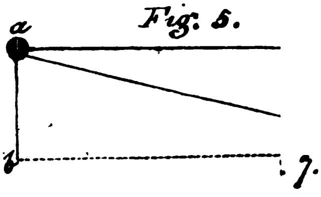


Fig. 5.



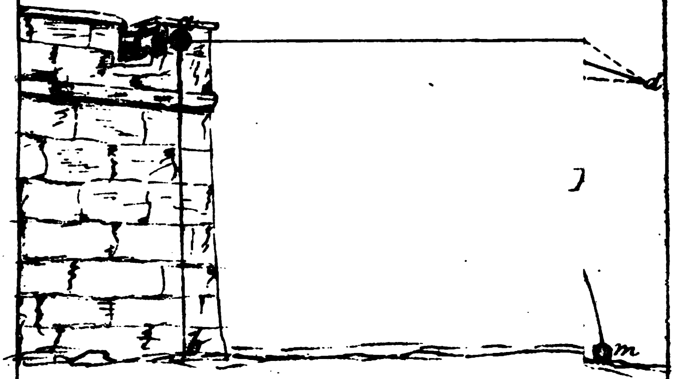


Fig. 9.

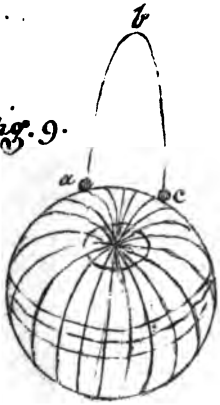
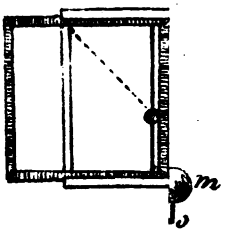


Fig. 8.



swings in the 24 hours, the error will be so many times multiplied, and consequently could not fail to produce a sensible error in the going of the clock in a few days, and it is with a view to the correction of such errors that a screw is always placed beneath the weight of the pendulum, by turning which the weight may be raised or lowered so as to shorten or lengthen the pendulum, and thus to cause it to vibrate with greater or less rapidity, and by a careful attention to this screw the going of any clock may be regulated.

In the better kind of clocks, or such as are used for the purposes of astronomy (see Longitude in Astronomy) this regulation would be inadmissible, because such clocks would be useless unless their rate of going could be depended upon, and as the rod will become lengthened and contracted with the natural changes of temperature in the atmosphere, many ingenious contrivances have been devised for maintaining an unalterable length, under the name of compensation pendulums. A straight grained rod of deal split in the direction of its fibres and free from knots is found less subject to change its length, with different degrees of heat, than any other known substance, and is therefore very frequently used for pendulum rods, but among the best and most elaborate contrivances for the same purpose are the gridiron pendulum, (so called from the parallel situation of its bars) and the mercurial pendulum invented by the late celebrated Mr. George Graham, and described by him in the Philosophical Transactions for 1726.

The general form of the gridiron pendulum is shewn at Fig. 12. Plate II, and usually consists of five bars or rods, the two external ones *f f*, and the central one being of steel or iron, while the two intermediate ones, shewn by dotted lines, are of brass. The weight *a* is fixed by a screw in the usual manner to the central steel rod, which passes freely through the bottom piece of metal *c*, while the upper end of the rod is screwed into the top piece *b*, which is supported upon the two brass rods, the lower ends of these are screwed into the piece *c*, and this piece is supported by the two external steel rods *f f*, which are screwed at their upper ends into *d*, and to the centre of this last piece the steel spring *e* is fixed by which the whole pendulum is supported. By this arrangement as the central and two external rods of steel become prolonged downwards by heat, the two brass rods will expand upwards, and as brass expands much more than steel with the same heat the shorter length of the brass rods will be found fully equivalent to the greater one of the steel, and consequently when the instrument is in good adjustment, the point of suspension and the centre of oscillation will always be kept at the same distance from each other, without any assistance or interference.

Fig. 13 shews the present improved form of the mercurial pendulum, *g h* being a straight steel rod with a screw formed on its lower extremity, working tightly through the metal cap *i*, into which is cemented the glass cylinder *k*, having a loose wooden cover to protect its inside from dust. About 7 inches in height of this cylinder is filled with quicksilver to constitute the bottom weight, and on account of the great expansive power of this metal by heat, the quantity mentioned will rise upwards, as much as the steel rod will expand downwards with equal temperatures, and thus the effective length of the pendulum will be preserved.

Since the pendulum requires a steady suspension, it becomes impossible to make use of it at sea in the chronometers that are used for determining longitude. These instruments must therefore be made with balances, such as are applied to common watches, except that they are so formed of brass and steel, as to answer the purpose of the compound or gridiron pendulum; for the balance of a watch performs the same part as the pendulum in a clock, and while such balance maintains an equal diameter in all temperatures, its beats in equal arcs will be isochronal or equal timed; such contrivances as produce this end are called *Compensation Balances,* but the difficulty is to maintain vibrations in equal arcs on account of the unequal action of the spring and wheels, and hence the use of *detached escapements,* or such as are so far cut off from the regular train of wheelwork as to be subject only to a momentary and equal impulse, instead of a continued and irregular one. The balance is however in no case so good as the pendulum, on account of its requiring a spring to produce its retrograde motion, and the necessity which exists of making it small, to avoid weight and consequent friction, and vis inertiæ: by being small its vibrations are frequent, and of course, if not perfectly isochronous a great and multiplied irregularity must be produced in the going of the machine to which it is attached, and from this and similar sources arise the great difficulties of constructing perfect chronometers for maritime purposes.

Before dismissing the subject of the pendulum, it may not be amiss to offer a few observations on the nature of Weights and Measures, and the means of procuring standards of reference for examining their correctness, because the pendulum seems to offer the most simple and convenient means of obtaining this end. The qualifications for such standards are that they should be simple and obtainable by any one who may be desirous of using them, so as to form a new and correct standard without recurrence to any former one which may have been lost or destroyed; and they must not be subject to wear, or to increase or diminish their dimensions by temperature or any other cause: a little consideration will show that weights must be dependent upon measures, for it is impossible to form any body into a weight without reference to its dimensions. The terms pound or ounce carry no specific ideas of their extent of weight to persons previously unacquainted with them; but if it is stated that four cubic inches of cast iron of a particular specific gravity will be equal in weight to a pound, or that a cubic foot of distilled or pure rain water weighs 1000 ounces, then such weights may be immediately formed by any one in possession of measures, and of course a standard lineal measure becomes of the utmost importance, as from it, weights to any extent may be determined.

Nothing could be more vague and unsatisfactory than the mode of determining primitive measures in England, either from vegetable productions, or parts, or actions of the human body, all of which must be liable to variation from a variety of causes; and yet we find that our inch was derived from three barley-corns laid end to end: and by an act of Henry III. cap. 51, it is ordained, that in order to regulate the weights of the realm, that quantity of metal which will balance 32 grains of dry wheat picked from the midst of the ear shall be called a pennyweight, that 20 such pennyweights shall make an ounce, and 12 ounces a pound; eight pounds of wine is by the same authority made a gallon, and eight gallons a bushel, and so on for larger weights and measures. Now as the large weights arise out of the multiplication of the primitive standards, viz. the grains of wheat which must vary with the soils and seasons in which they are produced, as well as their degree of dryness, it follows that such weights must be uncertain and undefined, besides which, a weight or measure ought in no case to be derived from a multiplication of its smallest foundation, since this may vary in too small a degree to be perceptible, while the multiplication of the error, however small, will produce a great difference in large quantities. To obviate this difficulty, the gyrd of the Saxons, which corresponds with our yard, was probably introduced as a proper measure of unity, and fathoms, furlongs, and miles, were made multiples of the yard, while the foot, the span, the palm, and the inch, might be considered as fractional parts of it. But in all these measures no certainty existed since the yard was determined by Henry I. to be the length of his own arm, while the foot, the cubit, the ulna or ell, the palm, the span, the hand, and many others are evidently derived from the dimensions of the human body. It was not, however, until the time of Henry VII. that any decisive measures were taken about obtaining more accurate weights and measures than had theretofore been in use, but an ordinance was then made, that a set of the most accurate and esteemed weights and measures should be collected and lodged in the Exchequer, as standards for the whole country to abide by, and with which all future weights and measures should be compared and examined. This regulation has been preserved and attended to ever since, and duplicates of the standards have been made with the greatest care and exactitude, and are deposited at the Tower, with the Royal Society, and in other places of security, to guard against the possibility of one set being lost or deranged.

Notwithstanding these precautions it is not impossible that by some great event the whole of these standards may be lost, and if this were the case, as they are arbitrary measures, it would be impossible to renew them with certainty unless some standard of comparison were established, and the only means which appear to offer themselves are, the mensuration of a degree of a great circle of the earth, or the length of the pendulum.

The first of these operations might appear impossible to any one unacquainted with the fact that it has actually been carried into effect several times, in a manner which will be noticed when speaking of the figure of the earth. It however requires most perfect instruments and observations, and is attended with such expense and trouble as to put it out of the power of most individuals; while the pendulum may be observed and measured at comparatively little or no expense of time or money. The French nation thought proper to adopt the former process, and after a series of most laborious and accurate observations, carried on for many years by their first mathematicians, ascertained that a quadrant of a meridian extending from the pole to the equator measured 5130740 toises, the ten millionth part of which was afterwards definitively decreed by the Legislative Body to be the *Metre* or standard of unity, upon which they were to form all their other measures whether greater or less. This metre accords pretty nearly with the length of a pendulum vibrating seconds, and may be considered as the present yard of the French, and as it ascends decimally, the next step or degree becomes the perch or decametre, the next the mile or kilometre, and then the myriametre or league, but the values of these several measures, as compared with those used in England, will be more clearly seen in the subjoined table.

The manner of using a pendulum to obtain a standard of measurement is simple, for it has been ascertained that although the sun performs an apparent journey round the earth from east to west in every 24 hours, with some irregularity, yet the stars do the same thing once in 23 hours 56 minutes with the greatest regularity, thus constituting the difference between a solar and a sidereal day. If then a small telescope be firmly and immovably fixed against a wall in such a direction that any bright star may be seen through it, that star will pass the telescope once in every 23 hours 56 minutes, and if a clock be placed near it, having a pendulum beating seconds, that clock will indicate the above portion of time between every transit of the star provided its pendulum be of the right length, and if not, it must be lengthened or shortened until it does keep time with it, which in the same latitude it can only do when it is of one particular length. A standard of length would thus be obtained which might at any time be resorted to, and which might be made the] *metre* or base upon which other measures could be constructed, and if it is objected that there is great practical difficulty in ascertaining the situation of the centre of oscillation with such nicety as to measure from it to the point of suspension, then the pendulum consisting of a straight parallel rod without a weight, might be resorted to, which would be easily measured, and would only have the effect of making the original standard 1-third longer.*

Having obtained an accurate standard of lineal admeasurement, solid measures, or measures of capacity, as well as weights, would arise out of it; and as pure rain water under equal temperatures, is less liable to a change of density and specific gravity than any other known substance, (see Section on Hydrostatics,) so it appears to be the best fitted for obtaining standard weights. A cube foot of pure water for instance weighs 1000 ounces, and either this measure, or the cube of the length of the pendulum, or an aliquot part of it, might be taken as the standard or base upon which to form larger and smaller weights, the same being whole and not fractional parts of the first quantity, and taken at a certain point of the barometer and thermometer. In this or a similar manner might a series of measures and weights be established, which it would be in the power of any one to adjust or examine with an apparatus of small expense, and without any very serious loss of time, while the weights and measures we at present possess and use are so very uncertain as to afford no greater proof of their accuracy, than the reliance which is placed in the correctness of their makers, unless indeed they have undergone the ordeal of a comparison with the national standards, which can never be expected in the great number that are made and sold.

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* For the truly scientific and accurate method of measuring the pendulum resorted to by Captain Kater, F. R. S. see the Philosophical Transactions, for 1818, Part I. or Philosophical Magazine, Vol. LII. page 90; and the Repertory of Arts, 2nd Series, Vol. XXXIV. page 77, where the same is detailed.

The following Table of the value of the new French weights and measures reduced into those of England, and of the comparative values of some English weights and measures, may be useful and interesting as containing particulars not generally met with in arithmetical tables:—

N. B. To obtain very small weights, such as fractions of a grain, take a grain of fine copper or other wire, such as is used for piano fortes, and divide its length with a pair of compasses into the required number of parts, which may be cut off with scissors, and will come very near to the truth.

MEASURES OF LENGTH.

1 Line, the 12th part of an Inch.	Inches. Decimals.	
3 Barley Corns	1.000	
A Palm, or Hands breadth (Scripture Measure)	3.648	
A Hand (Horse Measure)	4 000	
A Span (Scripture Measure)	10.944	
A Foot	12.000	
A Cubit (Scripture for Common Purposes)	18.000	
A Cubit (Ditto for Sacred Purposes)	21.888	
A Flemish Ell	27.000	
A Yard	3 *ft.*	0
An English Ell	3	9
A Fathom or Toise	6	0
A Pole	16	6
A Chain	22 *yards.*	
A Furlong	220	
A Mile	1760	

NEW FRENCH MEASURES.

		Eng. Inch. & Decim.		*Mil.*	*Fur.*	*Yds.*	*Ft.*	*Inch.*
Millimetre	=	0.039						
Centimetre	=	0.393						
Decimetre	=	3.937						
METRE*	=	39.371	=	0	0	1	0	3.37
Decametre	=	313.710	=	0	0	10	2	9.7
Hecatometre	=	3937.100	=	0	0	109	1	1
Kilometre	=	39371.009	=	0	4	213	1	10.2
Myriometre	=	393710.000	=	6	1	156	0	6

MEASURES OF CAPACITY.

		Eng. Cubic Inch. & Decim.		*Tuns.*	*Hogs.*	*WineGall.*	*Pints.*
Millilitre	=	0 061					
Centilitre	=	0.610					
Decilitre	=	6.102					
LITRE	=	61.028	=	0	0	0	2.113
Decalitre	=	610.280	=	0	0	2	5.135
Hecatolitre	=	6102.800	=	0	0	26.42	
Kilolitre	=	61028.000	=	1	0	12.19	
Myriolitre	=	610280.000	=	10	1	58.9	

The English Ale Gallon contains 282 cubic inches.
The Wine Gallon - - - - 231 ditto.

63 gallons Wine Measure, 54 gallons Beer Measure, and 48 gallons Ale Measure, each make a hogshead; 49 Ale pints contain 1727¼ cubic inches, and may therefore be considered (in round numbers) as a cube foot, which contains 1728 cubic inches; a cubic foot of pure water weighs 1000 ounces.

WEIGHTS.

		Eng. Grs & Decim.		AVOIRDUPOISE. *lbs.*	*oz.*	*dram.*
Milligramme	=	0.015				
Centigramme	=	0.154				
Decigramme	=	1.544				
GRAMME	=	15.444				
Decagramme	=	154.440	=	0	0	5.65
Hecatogramme	=	1544.402	=	0	3	8.5
Kilogramme	=	15444·023	=	2	3	5
Myriogramme	=	154440.234	=	22	1	2

The pound and the ounce in Troy weight and Apothecaries' weight are the same only differently divided and subdivided, and the proportions of a pound Troy to a pound Avoirdupoise is as 14 to 17, the former pound containing 5760 grains and the latter 7000. The Troy and Avoirdupoise ounce are therefore not alike, but 14 ounces 11 pennyweights and 16 grains Troy are equal to a pound Avoirdupoise. The drachm of Apothecaries' weight must not be confounded with the drachm of Avoirdupoise, the latter being much the smallest.*

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* For farther particulars respecting Weights and Measures, see Dr. Kelly's Metrology, 1 vol. 8vo. London.

When the weight of a body is mentioned it is always understood to be its weight when in a state of rest, or when moving so slowly as to be free from acceleration, for if this is not the case the apparent weight or effective force of such body will be increased by its momentum, in a ratio proportionate to its velocity of motion, as mentioned at page 20. In calculating the actual power of a weight to move machinery, it is not therefore sufficient to take the mere weight into account, but its rate of motion or velocity must also be considered, for if it moves through a given space at a certain velocity, or in a certain time, and produces a certain effect, it will produce a double effect by moving through the same space in half the former time, or in other words, it will produce the same effect by moving through half the former space with double its former velocity. Momentum or moving force arises out of the weight or quantity of matter being multiplied by the velocity of motion, and thus a very small body in rapid motion may become a balance in effect to a much larger or heavier one moving with less speed. Suppose for example that a cannon ball weighing 10lbs. moves at the rate of 100 feet in a second, and that a smaller ball which weighs but 2lbs. moves at the rate of 500 feet in the same time, then to compare their effective forces against any opposed obstacle, the 10lbs. must be multiplied by its velocity 100 which produces 1000, and the 2lbs. must be multiplied by 500 which also produces 1000, and thus it appears that the smaller body becomes an exact balance to the larger one, the first making out in motion what it wanted in matter, while the latter makes out in matter what it wants in motion, and upon this principle does the action of all the mechanical powers depend, as will plainly appear when they are explained. But before proceeding to them it will be necessary to make a few observations on what is called the Center of Gravity of Bodies.

: 31 to 40

Fig. 12.

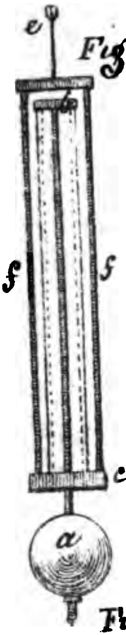
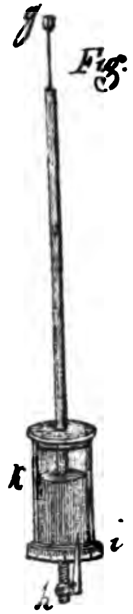


Fig. 13.



16.

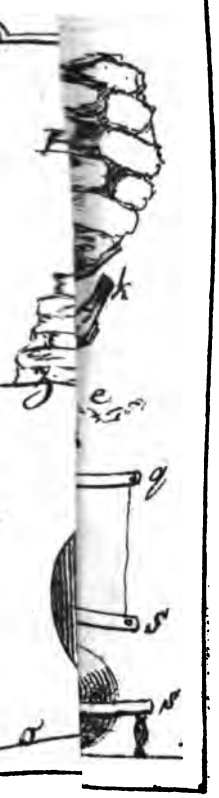


Fig. 18.

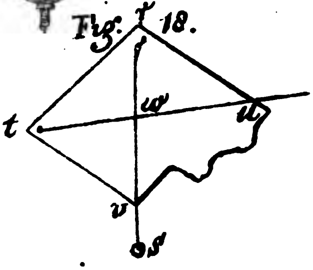
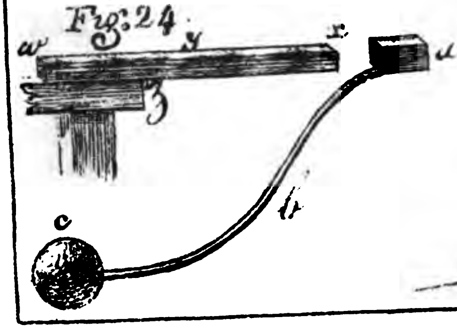


Fig. 24



MECHANICS.

SECTION III.

OF THE CENTER OF GRAVITY.

NOTWITHSTANDING each individual particle of which a body is composed is subject to the attraction of gravitation, and will consequently have weight, and the weight of all things is thus distributed throughout their whole extent, still there is a single point in every body in which its whole weight or gravitating influence seems to be condensed or concentrated, and this is called the *Center of Gravity* of such body. If therefore this center of gravity is supported or sustained, the body cannot fall, and whenever bodies do fall in obedience to gravitation alone, they will fall in the direction of a right line, which unites their center of gravity to the center of the earth, and which on this account is called the *Line of Direction;* and for the same reason as all bodies have a constant tendency to fall, their centers of gravity will in all cases get into this line, or immediately under the point from whence they are suspended, whenever such bodies are free to move, and they are suspended from any other point than the centre of gravity itself.

In order to come to a clearer comprehension of the nature of the center of gravity, and why this concentration of weight should take place in it, suppose *a b* Fig. 14, to represent a straight rod of wood or metal of the same size from one end to the other, and that *c* is its middle, if it is placed upon the top of the pin or point *d* directly under its center *c* it will balance, and it may be supported without any other assistance, because since gravitation acts in proportion to the quantity of matter, and there is an equal quantity in each end, or between *a* and *c*, and *b* and *c*, it follows that the end *a* will be drawn downwards with a force exactly equal to that which is acting upon *b*, and therefore a balance must ensue while the whole weight of *a b* will appear to be concentrated in the point *c* upon which it can be balanced, and which is consequently not only its center, but its center of gravity.

But if instead of supposing the bar *a b* to be of the same materials throughout, the end from *a* to *c* is presumed to be made of lead or any heavy material, and that from *c* to *b* is still of wood, then *a c* will contain more matter than *c b*, and will consequently preponderate, unless the pin *d* is removed from *c* to a point *e*, which will now be its center of gravity, and upon this it will balance as before, though it will now be seen that the center of gravity no longer coincides with the real center or middle of the rod which is still at *c*. It follows therefore that the center of gravity, and the center of magnitude or dimensions have no connection with each other, nor can they ever agree, or be in the same point except in regular homogeneous solids such as the globe, the cube, the cylinder, and the like, and when these possess equal density in all their parts their centers of gravity will be in their common centers.

The center of gravity is not however always in the center of the whole quantity of matter which a body may contain, of which one instance is offered in Fig. 15, where 5 and 1 are meant to represent two unequal sized balls connected together by a stiff wire between them, and balanced upon the point *f* in that wire, which is the center of gravity, and which is made to rest upon the pin *g*. In this case the larger of the two balls is supposed to weigh 5 ounces, and the smaller one 1 ounce. The quantities of matter on the two sides of *f* are therefore very different, and still a balance is produced, but to produce this it must be observed, that the wire from the point *f* to the center of the ball 1 is five times as long as it is from *f* to the center of the ball 5, and therefore if 5 falls one inch, 1 must rise five inches, and *vice versâ*, consequently here a degree of momentum will be generated that will produce a balance, for although the two bodies 5 and 1 are unequal, yet their masses multiplied into their respective velocities of motion will be equal, and consequently a balance will be produced as explained in page 40. The difficulty of balancing or supporting tall bodies arises from the circumstance of the center of gravity always endeavouring to get under the point of suspension. Thus *h* is the center of gravity of the lozenge-shaped figure *i k l m* Fig 16. which figure will be supported or balanced upon a pin, passing through it at *m*, so long as the centre of gravity *h* is immediately over the point of suspension *m*, but if that center is removed in the slightest degree either to the right or left of its place *h*, the body will no longer retain its erect position *i k l*, but it will revolve upon the point *m*, and place itself in the situation indicated by the dotted lines beneath the point *m*, and its center of gravity will now be removed to *n*, directly under *m*, and in the line *m o*, which is the line of direction, or line in which the body *i k l m* would fall to the earth, if it were at liberty to move. For the same reason it would be very difficult to balance the rod *a c b* Fig. 14, so as to keep it in a horizontal position if it were of considerable thickness, because if its ends vibrated upwards and downwards the center of gravity *c* would at every vibration be removed to that side of the pin *d*, which would be next to the descending end, and consequently the body would cease to be supported and must fall. To remedy this inconvenience in scale beams, which are required to be stationary when in horizontal equilibrium, the points of suspension are always placed above the beam as at *p* Fig. 17, which represents a common scale beam, consequently the centre of gravity will be at *q*, directly under those points when the beam is level, but not in any other position, and therefore such a beam will always assume the level position when equally loaded at each of its ends.

What has been above stated furnishes a very ready means of ascertaining the situation of the center of gravity of any plane surface which is portable, notwithstanding it may have the most irregular outline or contour. Thus suppose Fig. 18 to be such a surface, and a hole be made towards any of its extremities as at *r*, large enough to introduce a wire which will support it, and upon which it can move freely; that wire will be the point of suspension, and a plumb line with a weight hung upon that same wire as at *r s* will represent the line of direction, as extending from the point of suspension towards the earth's centre. It is known that the center of gravity of the irregular body *r t v u* will get under the point of suspension, and consequently will be somewhere in the line *r v* indicated by the plumb line, therefore let that line be marked upon the surface. Then make another similar hole in some other extremity of the body as at *t*, and introduce the wire and plumb line into this as before; the line of direction now shewn will be *t u*, and in some part of this, the centre of gravity must also be, but inasmuch as it cannot be in two places, so the intersection *w* of the two lines must show where it really is. When bodies are not portable, and will not admit of this kind of examination, their centers of gravity can only be ascertained by experiment or calculation, in which the weight, density, and situation of the respective materials must be taken into account, and having so ascertained the place of the centre of gravity, it will instantly be seen whether such body is firmly and securely supported or not.

An old wall in ruins formed like Fig. 19 might appear dangerous and incapable of standing, but if by calculation its center of gravity is found to be at *x*, and its line of direction is ascertained by a plumb line to be *x y*, it is evident that if the cement holding the stones together is so strong as to keep the wall from separating it cannot fall, because the line *x y* is within the supported base *z a*, but on the contrary had it extended beyond *a*, it would have been without support and must have fallen.

The same reasoning applies to leaning towers and steeples of which there are many examples in the world. The tower at Pisa in Italy is one of the most remarkable among these, it being 182 feet high, and leans no less than 16 feet out of the perpendicular, and has done so without detriment above 300 years. The two steeples at Bologna also lean, and were described as doing so antecedent to 1586. At Corfe castle and Caerphilly in South Wales, there are examples of the same sort, as well as at Bridgenorth, and several other places.

The reasons why the Cone and the Pyramid should be the strongest figures, and why high carriages, or those loaded on their tops, should be much more likely to be overturned than low ones are also apparent on the same principles. Thus let *b* Fig. 20 represent a load of stones or iron contained in a cart moving upon the rounded or sloping road *c d e*, this load being low down in the cart, *b* will also represent its centre of gravity, and *b f* its line of direction, which it will be seen falls much within the supporting or lower wheel *g g*, and therefore such cart cannot overturn, but in the load *h* the center of gravity is elevated from its former position to *h*, and *h i* is the line of direction, which falling without the base or wheel *k* the load will be unsupported and must consequently fall.

Many mechanical deceptions are practised by removing the center of gravity from its natural into an artificial situation, or by disguising its place; thus a cylinder placed upon an inclined plane may be made to run up hill instead of down, a double cone appears to run up hill, and many balances are effected, which to the uninstructed appear highly astonishing. In the first case a large cylinder of wood is prepared, and its centre of gravity is removed from its actual center *m* Fig. 21, where it would otherwise be to *l*, by the introduction of a plug of lead near its edge as at *l*, in consequence of which *l n* becomes the line of direction, and *l* will descend towards *n*, in doing which it will carry the cylinder a short distance up the inclined plane *o p*. The double cone in like manner appears to run up hill, although in fact its center of gravity is lower at the top than at the bottom of the inclined plane in consequence of its peculiar shape, for the double cone is placed upon two rods or sticks *q r*, *s r* Fig. 22, meeting at an angular point at *r*, and diverging at their opposite ends *q s* to a distance very nearly equal to the length or axis of the cones, it follows therefore that when the double cone *t v* is placed near the point *r*, its form will not permit it to enter between the two rods, but as it proceeds towards *q s* it will sink between them, until at last it is merely supported by its two points *t v*; now notwithstanding *r* is the lowest end of the inclined plane, as shewn at Fig 23, yet it will be seen that the double cone is much more upheld in its situation *t* than it is at *v*, and that although it appears to run up the inclined plane from *r* to *s*, yet in fact it is all the time actually descending in the direction of the dotted line *u s*, for at *t* it is full an inch from the table, while at *v* it touches it, and consequently the appearance of running upwards is altogether a deception.

A stick *w x* Fig. 24, which is incapable of supporting its own weight on account of its center of gravity *y*, being beyond the edge of a table *z* upon which it is lying, may become supported by having an addition of weight made to its unsupported end *x*. That weight must however be in a form resembling *a b c*, *a* being a socket of tin made to fit tightly upon the end *x* of the stick, *b* a stiff wire soldered to it, and *c* a lump of lead placed at such a distance from *a* as to project underneath *w*. The center of gravity of the whole compound piece will now be removed from its former situation *y* to *c*, and it will therefore be supported by the table *z* without any danger of its falling. Many other instances might be named, but the above are presumed to be sufficient.

SECTION IV.

OF THE MECHANIC POWERS.

THE mechanic powers are certain simple arrangements of machinery by means of which weights may be raised or resistances overcome with the exertion of less power or strength than is necessary without them. In a mechanic power the weight or resistance to be moved, and the power or strength which moves it, should both move at the same time; and any thing constitutes a mechanic power in which the motion of the power produces a simultaneous motion in the resistance, provided less power is necessary than is due to the weight or strength of such resistance. From this general definition it might appear that every machine capable of generating force would be a mechanic power, but simplicity is likewise essential, and hence the mechanic powers may be said to be the elements of machinery, and they are in fact so elementary, as to admit of no simplification or alteration.—They are but six in number, and the names by which they are distinguished are the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Wedge, and the Screw, and out of the whole, or a part of them, it will be found that every mechanical engine or piece of machinery is constructed.

Since the effects of the mechanic powers depend upon a balance being obtained between an unequal power and resistance, it follows that although their motions are simultaneous they can never be equal, for if this were the case the quantities of momentum would be unequal, and no balance would be effected. The respective motions of the power and resistance will therefore always be to each other as the magnitude of such power and resistance, and all that has been said of Fig. 15 applies to the mechanic powers in general, for if the center of the ball 1 be five times as far from the point of balance *f* as the center of 5 is from it, then whenever 1 is moved it will move five times as far as 5 does, and will thus generate five times the momentum, consequently the ball 1 will be a balance to the ball 5, although this last is five times as heavy as the first; and thus it is seen that although power may be gained by the use of a mechanic power, a proportionate loss of time will ensue, or in other words, if a certain weight can be raised to a certain height by unassisted strength, and the same thing is afterwards done with one-tenth part of the exertion through the use of a mechanic power, it will be found to occupy ten times as much time. In many cases however loss of time is not to be put into competition with the ability to do a thing, and since the advantages which the mechanical powers afford to man, by enabling him to perform feats, which without their assistance would have been for ever beyond his reach are incalculably great, the waste of time is in general overlooked, and is much more than balanced in the general result.

THE LEVER

Being the simplest of all the mechanic powers is in general considered the first.—A Lever is an inflexible bar or rod of any kind or shape, so disposed as to turn on a pivot or prop, which is always called its *Fulcrum*. It has the weight or resistance to be overcome attached to some one part of its length, and the power which is to overcome that resistance applied to another; and as the power, resistance, and fulcrum admit of various positions with regard to each other, so the Lever is divided into three modifications, distinguished as the first, second, and third kinds of Lever: that portion of it which is contained between the fulcrum and the power being called the acting part or arm of the Lever, and that part which is between the fulcrum and resistance, its resisting part or arm.

In the Lever of the first kind, the fulcrum is placed between the power and the resistance; in the second kind, the resistance is between the fulcrum and the power; and in the third kind, the power is applied between the fulcrum and the resistance; and the power gained will in all cases be in proportion to the relative lengths of the two arms in the same lever. Fig. 25. Plate III. represents a Lever of the first kind, in one of its most common applications, viz. raising a large stone or weight *d*, and when used in this way it is, in practice, most commonly called a Crow-bar, or Hand-spike. The entire bar *e f* is however a lever, and the stone or block *g* is the fulcrum upon which it turns, consequently from *g* to *f* (where the power is to be applied) will be the acting part of this lever, and from *g* to *e* its resisting part. The power gained by this form of lever is as the resisting is contained in the acting part, or as *f g* is to *g e*, so that if the lengths *f g* and *g e* be taken, and *f g* is divided by *g e* the quotient will be the power gained. In the plate *e g* is contained twice in *g f*, or will gain a power of two, so that whatever the weight of *d* may be, it will only appear to weigh half as much at *f*; and if the fulcrum *g* were removed so much nearer to *e* that the new distance between *e* and *g* should be contained twenty times in the distance *g f* then a power of 20 would be gained, or *d* would be lifted at *f*, with a power equal to 1-20th of its real weight. In this case however *f* would have to descend 20 times as far as *e* would rise, and therefore a very small motion would be communicated to *d*.

By the same rule, if moving the fulcrum *g* towards the resistance *d* increases the power of the lever at *f*, so will removing it in a contrary direction, or towards *f* decrease it. Thus if *g* is supposed to be placed exactly half way between *e* and *f*, so as to make the acting and resisting arms equal, then no power at all will be gained at *f*, because whatever may be the weight placed on *e*, an equal power will be necessary to move it at *f*, and as both *e* and *f* will in moving perform equal arcs of circles, or move through equal distances in equal times, so no power can be gained, this being in direct opposition to the laws of motion. Again, if the fulcrum *g* be supposed to be placed nearer to *f* than it is to *g*, then *e* when moved will pass through a larger space than *f*, therefore *e* will generate more momentum than can be generated at *f*, and consequently the apparent weight of *d* as felt at *f* will be increased, or a greater power must be exerted at *f* than is equivalent to the weight of *d*. Under such an arrangement it will be evident that although the whole is a lever, it cannot be a mechanic power, unless it is admitted that from *f* to *g* is the resisting end, and from *g* to *e* the acting one; in this case the power must be applied at *e* instead of *f*, and now it will be seen that it is the same lever as in the first case, but with its ends reversed.

In speaking of the power of levers, under all their several modifications, it must be observed that they must be considered as without weight, and in making accurate experiments upon them, the weights of their several parts must be nicely balanced, otherwise the result will be affected. Thus in Fig. 25, if the bar *e f* were of equal size throughout, it is evident there would be twice as much matter in the arm *g f* as in the shorter one *e g*, and this additional quantity of matter would preponderate and bear down the end *f*, thus appearing to increase and assist the power. This difficulty will be met in theory by considering the whole bar *e f* as without weight, and in practice or experiment it must be obviated by hanging on a weight, or making the shorter arm *e g* so much thicker, as to cause it to be an exact balance for the longer arm *g f* when the lever is not in action.

From the above description it will not only appear that all the various kinds of scissors and pincers, which turn upon a central screw or rivet, are levers of the first kind, but that the scale beam, and statera or steel yard, with which a number of weights can be ascertained by comparison with one unchangeable weight, are of the same class. The scale beam is an instrument of such universal use that it demands a little further consideration. Though a Lever, it is in no case intended to be used as a mechanic power, but when perfect it ought to indicate most correctly when equal weights are appended from its opposite ends, or placed in the scales which are generally attached to them. Accordingly following what has been stated in the explanation of Fig. 25, at page 51, in the second case, or where the fulcrum is placed half way between *e* and *g*, it is absolutely necessary that the fulcrum or pivot upon which a scale beam hangs and turns, should be precisely half way between its two extreme ends where the scales hang, for if one end of the beam is longer than the other, that end will have an advantage of power, and consequently, although the beam may balance and appear to be good if the two scales are made of different weights to produce that balance, yet so soon as equal weights are placed in them the balance will be lost, and that which hangs to the longest end will always preponderate. In order therefore to try the goodness of a pair of scales, the scales should be taken off the beam to ascertain if the beam balances without them; they should then be put on again, and afterwards reversed; or each scale hung to the opposite end of the beam which it before occupied. Equal weights should then be put into the opposite scales, and these should in like manner be reversed or changed, and if the beam maintains its horizontal position under all these changes it may be relied upon as being good and perfect. The pivots or fulcrum *p* Fig. 17, Plate II. upon which the beam turns ought to be sharp, or knife-edged, as it is termed, and they should be of steel well hardened, as well as the interior of the ring in which they move; this confines the fulcrum to a minute line and prevents friction. In beams for nice purposes the pivots ought not to be too much elevated above the center of gravity, for the reasons stated in page 43, for although this center will generally be found an inch or two below the pivots in strong warehouse beams, in order to bring them to a speedy equilibrium by which time is saved, yet for accurate weighing the nearer the center of gravity is brought into the straight line that would connect the tops of the two scale eyes *h h*, and the under side of the pivot *p* the better, although such a beam will occasion great loss of time by its vibrating a long time before it becomes stationary. The index *i* is for showing when the beam is in an horizontal position, it being more readily seen by this, than by the beam itself.

The form of the statera or steel yard is shewn at Fig. 26, *k i* being a lever or bar of iron turning upon the fulcrum *k*, which moves in rings attached to the hook *l*, by which the whole machine is in this case supported, *m* is the body to be weighed, which hangs from the pivot *n*, and of course *n k* is the resisting part of the lever, while *k i* or from *k* to any situation *o* of the constant weight (which shifts into all the several notches marked 1, 2, 3, 4, &c. to 15) will be the acting end of it. Now taking this lever to be without weight, or admitting that it is balanced upon *k* by the greater quantity of matter in its end *h*, it follows that while the distances *n k* and *k o* (or 4) are equal, that any weight *o* will balance an equal weight *m*, and therefore if *o* be 4 pounds *m* must be the same, while if *o* be removed towards *k* its effect will be so far diminished that it will no longer balance its own weight, but will merely be equivalent to 1; 2, or 3lbs. hung at *m*, as indicated in the figure, and on the contrary, if *o* be removed towards *i*, as far as 8 for instance, now the acting arm *k* 8 will be twice as long as that from *k* to *n*, and therefore *o* will have its power doubled, and will balance 8lbs. hung upon *m*, and so for any other amount. It will be observed in the above description that the hook *p* shewn in the figure is quiescent and useless, but most steel-yards are made with double fulcra, by which their extent of scale in weighing becomes much increased, although with some little sacrifice of accuracy. Thus suppose that the hook *m* were to be turned over the point *h* until it assumed the dotted position shewn at *q*, and that the whole instrument were to be inverted so that *p* should become the hook, by which it is to be suspended instead of *l*;—*l* will now become the useless hook, and the matters to be weighed will still be hung to *q*. The former fulcrum *k* is now abandoned, and a new one *r* called into action, while the weight *o* assumes the dotted position shewn above it, as will be clear if the plate is inspected with its wrong side upwards. From the great proximity which now exists between *r* and *n*, the resisting part of the lever is much shortened while its acting part from *r* to *i* is effectively lengthened, and consequently the power of the weight *o* is proportionably increased, as indicated by a new set of figures engraved on the opposite side of the rod *k i*.

In making experiments upon the Lever, a straight kind of scale beam made of wood or metal, and divided into equal parts like *s t* Fig. 27, will be found the most convenient apparatus; it is supported on a stand *v*, and if two equal weights *u* and *w* be hung at equal distances from its fulcrum or center they will balance, and their quantities of motion will be found equal, but if *w* be taken away, and another weight *x*, six times as heavy as *u*, be hung six times as near the center as *u* is, they will still balance, and *x* will be found to have but 1-6th part of the motion of *u* in equal times, hence if the power of a Lever of the first kind is very great, it will be found incapable of producing much motion, and therefore is but limited in its application.

Fig. 28 shews the same apparatus arranged for shewing the nature of a Lever of the second kind, in which the resistance is between the fulcrum and the power; *a* being the fulcrum, *b* the weight or resistance to be lifted or overcome, and *c* the part at which the power is to be applied, which in this case is represented by a weight *d* attached to a string passing over the fixed pulley *e* (which does not alter the action of the weight *d*, as will afterwards appear) and ending in a loop at *c*. It is evident from this disposition of the several parts, that if the weight *b* were placed in close contact with *c* it would exert its whole gravitating influence upon the string, and could only be supported or balanced by making the weight *d* equal to itself, and consequently no power would be gained. Again, if the weight *b* were to be moved close to *a*, or indeed put over it, then it is also evident that the entire weight of *b* would be sustained by the fulcrum *a* alone, and the end *c* would be relieved from all participation in it; consequently in shifting *b* from *a* towards *c* its effective power upon the end *c* would gradually increase from nothing to its entire weight, and therefore in every situation except *c* the weight *b* would be lifted with less force than is due to its gravitation, or a power would be gained. In the figure *b*, is represented as half way between *a* and *c*, and therefore half its weight will be supported by the fulcrum *a*, and the remaining half is left to be balanced by the power at *c*, consequently such an arrangement gains a power of 2 for whatever the weight of *b* may be, it will require but half that weight to balance it at *d*. In this lever from *c*, or the point where the power is applied, to the fulcrum *a* is the acting arm, and from the fulcrum to the place of the weight or resistance (*b* for instance) is the resisting one, and the power gained by this lever, as in one of the first kind will be found by dividing the length of the acting arm by that of the resisting one; or indeed the powers of all levers may be found by stating the following proportion: as the distance between the power and the fulcrum is to the distance between the resistance and the fulcrum, so is the resistance to be overcome, to the quantity of power that will balance it.

Numberless instances of the application of this lever occur, among which may be noticed the common cutting knife, used by last and patten makers, one end of which is fixed to the work-bench by a swivel hook; and two men carrying a load between them, by one or more poles, as a sedan-chair, or as brewers carry a cask of beer, in which cases either the back or front man may be considered as the fulcrum and the other as the power, and while the weight is equidistant between them, they will each bear an equal portion of the load, but if otherwise that man nearest to it will be most incumbered. The same circumstances occur in a four-wheel carriage, consequently, if the wheels are of equal diameter the load should be placed exactly between them, to produce an equal distribution of it upon all the wheels when upon level ground. A door hung upon hinges, and a wheel-barrow, are other instances of this modification of lever.

The third kind of Lever, or that in which the power is applied between the fulcrum and the resistance, cannot be called a mechanical power, although it must be mentioned as a modification of the Lever, for since its resisting arm is in all cases except one, longer than the acting arm, and in that one case is equal to it, so it can never gain power, but in most of its arrangements must loose it. If the power and resistance represented in Fig. 28 be conceived to change places with each other, then that figure will present a Lever of the third kind, for now *b* will be the power which is placed between the fulcrum *a*, and the resistance at *c*, for the purpose of overcoming it, and since, if both the power and resistance were acting at *c* they must be equal to each other, while the power must be increased in proportion to its proximity to *a*, so it follows that this Lever must loose power whenever it is applied at any other situation than *c*, and that even there it can gain none.

The most familiar examples of the occurrence of this kind of Lever are in the use of common fire tongs, and in rearing a tall ladder against a wall: but the circumstance that principally gives it importance is, that the limbs of men and all animals are formed of it, for the bones are the levers, while the joints are the fulcra; and the muscles which give motion to the limbs, or produce the power, are inserted, and act close to the joints, while the action is produced at the extremities. The consequence of this is, that although the muscles must necessarily exert an enormous contractile force to produce great action at the extremities, yet a celerity of motion ensues which could not be equally well provided for in any other manner.

Levers may be combined together, either for the purpose of increasing their power, or producing this celerity of motion. Thus Fig. 29 shows a compound Lever of the first kind: the first Lever *e* having its resisting to its acting part, as 1 to 2, will reduce the weight *f* to one half at the point *g*; *h* is a similar Lever connected to *e* by a string between *g* and *i*, and by which the half-resistance at *g* is again subdivided, and becomes a quarter of *f* at *k*: *l* is a third similar Lever disposed and proportioned as before, by which the resistance at *k* is again divided, and reduced to 1-eighth at *m*; and a similar series might be constructed to any extent, but at last the motion of *f* would become almost imperceptible, for even in this extent of combination, when motion is communicated to *m*, it will require that *m* should descend 8 inches in order to move *f* one inch. If on the contrary a small motion is communicated to *f* it will become magnified in a like proportion at *m*, and hence such an arrangement is convenient and is often resorted to, in order to render small motions perceptible, as in the Lever Pyrometer invented and described by Mr. Ferguson. The Pyrometer is an instrument for showing the quantities of expansion and contraction, which take place in different metals or other substances with certain temperatures, and is therefore highly useful in experiments to determine the best materials, and the proportions of them to be used in the formation of compensation pendulums and balances, (see page 31.) Fig. 30 shews the Lever Pyrometer, in which *n o* is the bar of metal to be experimented upon, and which for this purpose is placed between the adjusting screw *p* and the lever *q*, of which *r* is the fulcrum or pivot, and from this pivot to the place upon which the bar presses is made just 1-tenth of the distance that exists between the point of the bar and the upper end *s* of the lever. This end presses upon the second lever *t v* at 1-tenth from its pivot at *t*, and consequently if the bar *n o* expands or contracts but the 100th part of an inch it will cause the end *s* of the first lever to move the 10th of an inch, and this will in like manner make the end *v* of the second lever move over a whole inch on the graduated scale *r w*. Every 10th of an inch on this scale will therefore be equivalent to the thousandth part of an inch of expansion in the bar *n o*, and thus such an instrument indicates very minute changes, but is not accurate for great motions, because when the levers move the parts between their fulcra and the points of contact become extended, and cease to be tenth parts of their respective lengths: *x* is a very slight spring to cause *t v* to return, and *y* is a spirit lamp for heating the bar, but in making accurate experiments with this instrument the heat must not be communicated directly to the bar, but to a small cistern, through which the bar is made to pass, and which may be filled with water, oil, or any other fluid, through which the heat is transmitted while its temperature is shewn by a small mercurial thermometer placed within it. The best and most accurate pyrometers are made with clockwork, for these act equally well to any extent of expansion.

From the account given by Lord Macartney it appears the Chinese were acquainted with the advantages to be derived from combining Levers, and that they had a most simple and ingenious method of dividing a great load among a number of men who have to carry it, this is represented in plan, or as looked at from above by Fig. 31. The load shewn at *a* is fixed like a sedan chair between the two strong poles *b* and *c* at an equal distance from their ends; to these ends four transverse pieces are attached, and the ends of these are again fixed to the middles of the 8 pieces marked *d e*, each end of which is supported on the shoulder of a man, so that upon the principles of the Lever of the second kind it will be seen that the load *a* is equally distributed among 16 men, one being placed at each point *d* and *e*. Nearly the same effect is produced in harnessing the leading horses to our four-horse coaches in England, by what are called swivel bars: thus the bar *f g*, Fig. 32, is fixed at its center *h* to the pole of the coach, and the two minor bars *i* and *k* are fixed at their centers to *f* and *g*, the traces are attached to the ends of *i* and *k*, and consequently the load at *h* is equally divided between the two horses drawing at *i* and *k*. If one horse should be stronger than the other, then a proportionate distribution of the labour may be made, by making the attachment at *h*, out of the center of *f g*, and letting the weakest horse draw at the longest arm.

The Lever has hitherto been treated and described as a straight inflexible bar for the sake of simplicity, but whether it be straight or crooked, flexible or stiff, still its effects will be the same, except only that variations may take place in its powers from an effective change in the relative length of the arms by change of position, for reasons that may not be apparent at first sight; for the actions of bent levers do not in all cases follow their material formation, but frequently assume artificial arrangements, that have no sensible appearance, but which may be investigated by the rules already advanced. Thus if the line *l*, *m* Fig. 38, be supposed to represent a straight lever with equal arms turning upon a fulcrum or center *n*, it will follow that the two equal weights at *l* and *m* will balance each other in the horizontal position. But they will do the same thing if the lever be conceived to turn upon its center *n* into the position *o p*, for since the gravitating influence of the weights while at *l* and *m*, or at *o* and *p*, or indeed in all other situations which they can assume, will be at right angles to the horizon, or to the horizontal line *l m*, so their effective action will be represented by perpendicular lines situated like those dotted from *p* to *r*, and from *o* to *q*, or by others parallel to them; and since these lines must in all cases cut the horizontal line *l m* at equal distances, such as *n r* and *n q* from the fulcrum, so it follows that the two weights must balance each other in all positions. If a crooked lever is taken instead of a straight one, but which still has equal arms and equal weights, as

e 50 to 61.

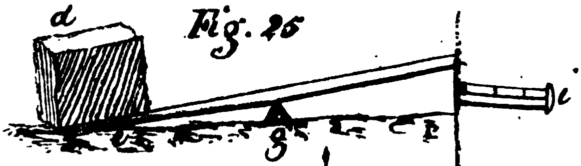


Fig. 26

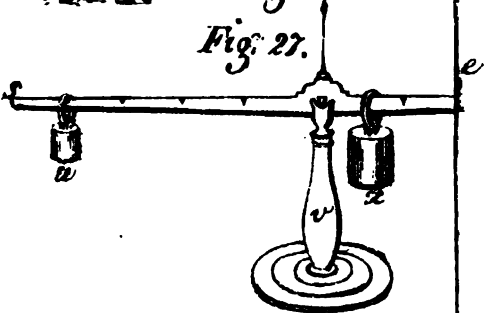


Fig. 27.

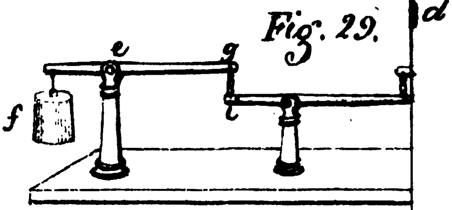


Fig. 29.

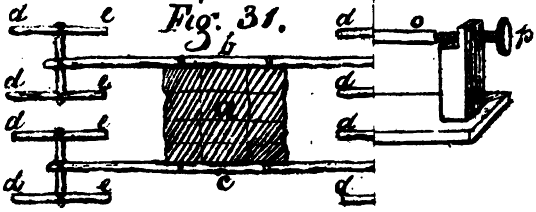


Fig. 31.

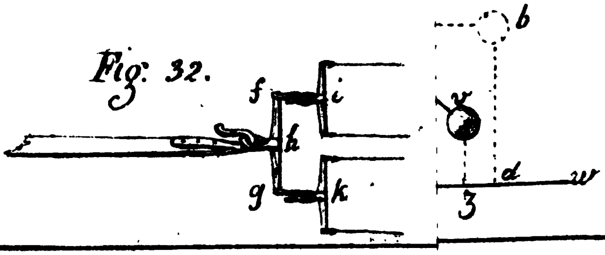


Fig. 32.

s t v Fig. 34, and *t* be taken as its fulcrum or pivot, an horizontal line must be drawn as before to estimate its power when acted upon by weights, therefore let the line *u w* be drawn, and from the fulcrum *t* let fall the perpendicular *t x*, which will show the effective point of the fulcrum to be at *x* in the line *u w*. In like manner draw the lines *s y* and *v z*, from the centers of gravity of the weights and parallel to *t x*, and the two distances from the fulcrum *x y* and *x z* will be found equal, and will represent the effective arms of such lever instead of the two distances *t s* and *t v* measured on the lever itself; under these circumstances an equilibrium must ensue. But if the lever *s t v* is conceived to be drawn out of its first situation into that of *a t b* the balance will be at an end, for although the position of the fulcrum *x* remains unchanged upon the line *u w*, yet the lines *a c* and *b d* will now represent the effective actions of the weights *a* and *b*, which are still equal, while the distances *x c* and *x d* are no longer so, and consequently to regain a balance in the new situation of this lever, the weight *a* must be increased as much as the distance between *x* and *d* exceeds that between *x* and *c*. The effective action of a lever may therefore be very much altered by its form, and the manner in which the power and resistance are applied to it, of which there are numberless instances in practice; a bent lever will also determine a number of weights by means of one, as well as the steel-yard; thus conceive the weight *s*, Fig. 34, to be considerable, and that no weight should be attached at *v*; the arm *t s* will then hang in the direction *t x* and the end *v* will be elevated, but a very trifling weight hung upon *v* will drive *t s* in a slight degree out of the perpendicular direction towards *a*; if the weight *v* is increased until it be equal to *s* then the lever will assume the position *s t v*, and if *v* is made superior to *s* then *v* will fall down towards *x*, and *s* will become elevated, consequently if the arm *t v* or *t s* be made to pass over a graduated or divided circle having its center in *t*, and having the weights corresponding with the different elevations marked upon it, it will become *A Bent Lever Balance.*

The next Mechanic Power is

THE WHEEL AND AXLE,

Which consists of two parallel wheels, pullies, cylinders, or circles, having one axis in common, as shewn at Fig. 35, Plate IV. *e e* being the pivot or common axis upon which the whole turns, *f* a cylinder, and *g* a larger pulley upon it; *g* would in this case be called the wheel, and *f* the axle, notwithstanding *e e* is the actual axis; and the same terms would be made use of whatever might be the proportionate size of *f* to *g*, provided *f* does not exceed *g* in diameter when the terms would be reversed. In using the wheel and axle, the power is applied to the edge of the wheel, and the resistance to that of the axle, and the advantage gained is as the diameter of the one is to that of the other. If therefore a string or rope be coiled round *g*, and another round *f*, in opposite directions, depressing the weight *h* will uncoil such cord, whereby *g* will be turned, and with it *f*, which will cause the weight or resistance *i* to ascend, and if *f* be half the diameter of *g* then *i* will be raised with half the power at *h*, which is due to its resistance, and *h* will move with double the velocity of *i* in the same time. Again, if the diameter of the wheel *g* be supposed to be 50 times that of its axle *f* then any weight at *f* will be raised with 1-50th part of the exertion at *g*, that would be necessary to raise it without a mechanic power, but it will move with only 1-50th part of the velocity.

The power of the wheel and axle has been described to be as the respective diameters of the wheel and the axle, but from the proportion that holds good in all circles between their radii, or semidiameters, their diameters, or their circumference, it is indifferent which term be taken, so that the same term be used throughout, consequently the powers will also be as their respective radii, or as their circumference; if therefore the wheel and the axle are of the same diameter no power can be gained, for one will do as much as the other, and a balance between the power and resistance must ensue. It is not however necessary that a rope should be coiled round the wheel *g*, or even that such a wheel should have the form or appearance of a wheel, for if the cylinder *f* only existed without *g*, and a lever, stick, or handspike, could be fastened or inserted into *f*, in such way, that the outer extremity of the lever would describe a circle round *e* of the same diameter as *g*, that circle would be the representative of the wheel *g*, and would gain the same power; hence the capstan used on board of ships, and upon quays for hauling ships into harbour, is a wheel and axle, although it may appear to be but an axle without the wheel. The handspikes become the wheel, and the circle in which the men walk and exert their power upon them gives it its diameter. If *f* and *g* were used as pullies, (or riggers, as they are technically called in this case) to communicate motion to machinery by bands or straps passing over them, their powers would still remain unchanged, and this would likewise be the case if the edges of *g* and *f* had teeth formed on them, for all wheelwork such as is used in clockwork or machinery consists of wheels and axles, the axle being the pinion, while the wheel retains its proper name, and hence the powers of all wheelwork must be calculated on the principles of the wheel and axle, viz. by dividing the radius of each wheel by the radius of the pinion that is fixed to it. The reason of this rule will be evident upon inspection of Fig. 36, which is a front view of Fig. 35 *k* representing the large wheel with its weight of power *i*, and *m* the smaller wheel with its weight of resistance *h*, and *e* is the axis; the force of *i*, which is tending to turn the wheel *k* round, will be represented by its radius *l e*, or the line passing from its outside to the center *e*; the force which is operating in the wheel *m* to raise the weight *h* will likewise be represented by its radius *n e*, and thus the whole line *l e n* is a lever of the first kind, *e* being the fulcrum, while from *l* to *e* is the acting, and from *e* to *n* its resisting part. The action of the wheel and axle is therefore reducible to that of a lever of the first kind, but in the lever the quantity of action is very limited, while in the wheel and axle, from all the radii being equal, a succession of imaginary levers like *l e n* will be generated so long as the wheel turns, and consequently its duration of action is unlimited, and it will raise a weight to any required height.

One of the most common practical applications of the wheel and axle is the crane used on wharfs and in warehouses, for raising and lowering heavy parcels of goods: formerly it was a very common practice to work such cranes by a man walking in the inside of the large wheel, which was thus put into motion in the same way that circular cages are moved by an inclosed squirrel, or that the turnspit dog was formerly used for roasting meat; this was, however, not only a dangerous but a very disadvantageous mode of employing strength, and is now almost entirely abandoned. The best and most efficacious method of employing human power to a vertical wheel and axle is to cover the exterior circumference of the large wheel, with float or projecting boards like a common water wheel, and to permit a man or men to tread upon the boards as in walking, at the height of a line which forms the horizontal diameter of the wheel, for then the man's whole weight and power will be thrown into action at the point where it will have the greatest effect. This application of power was invented and first used by Mr. David Hardie, and will be found fully described in detail, under the title of *Hardie's Crane,* in Dr. Gregory's Treatise on Mechanics, Vol. II. page 166, 3d edition.

The wheel and axle is sometimes used to multiply motion, instead of to gain power as in the multiplying wheel of the common roasting jack, to which it is applied when the weight cannot conveniently have a long line of descent, a heavy weight is in this case made to act upon the axle, while the wheel, by its greatest circumference, winds up a much larger quantity of line than the simple descent of the weight could require, and thus the machine is made to go much longer without winding, than it otherwise would do.

It is also useful for regulating unequal powers, thus common watches or spring clocks are made to move or go, by winding a thin spiral steel spring, like *o* Fig. 37, round a fixed post or center pin *p*, by turning the barrel or case *q q r*, which contains the spring in the direction of the arrow, while the outer end of such spring is fixed to the barrel at *r; r* will therefore revolve round *p*, and in doing this the spring will coil round *p*, and will at first exert little force to return into its former open position, but its power will increase with the winding, and whenever it is set at liberty it will uncoil and thus cause the barrel *q r q* to turn in a direction opposite to that of the arrow, but with a force decreasing as the spring uncoils, and it is this variable power which is applied to make the watch move.

A variable force would however cause the machine to go with variable velocity, and would therefore be inapplicable to clocks or watches, but by means of a variable wheel and axle the force is rendered equable. This variable wheel and axle is called a Fusee, and is that conical barrel seen in most watches round which the chain coils in the act of winding up. It is shewn at *t* Fig. 37, in which *s* represents the barrel containing the spring as at *q q r*, and the chain *v* which is wound round this is again withdrawn and is disposed around the conical fusee *t*, by applying the watch key upon the square *u* and turning it round.—When the fusee *t* is full of chain, or the watch is wound up, the spring, through the medium of the chain will act upon its upper part, which being very near the center will give the spring but little power, but as the spring uncoils and diminishes in strength it will act upon a larger part of the fusee until at last it gets to the bottom of it, and consequently, if the several increasing grooves upon *t* are made to increase in the same proportion as the power of the spring decreases, an equal power will always be acting upon the toothed-wheel *w* which gives motion to all the works.—*x* is a ratchet or click-wheel fixed upon the bottom of the fusee to permit its being turned in one direction without affecting the wheel *w*. All wheelwork consists of combinations of wheels and axles, and must have its power computed accordingly, viz. by comparing the radii of the several pinions with those of the wheels fixed upon the same pivots or arbors.

THE PULLEY

Is the next Mechanic Power, and is of very extensive application. In practice the pulley itself is generally called a *sheve*, the frame that contains it a *block*, and the rope a *fall*. From what has been said of the wheel and axle, and of the mechanic powers in general at page 49, it will appear that a single pulley, disposed as at Fig. 38, can give no mechanical advantage, because if two equal weights *x* and *y* be fixed to the two ends of a cord passing over the pulley *z* they will act at the points *a* and *c* being the terminations of two equal radii *a b* and *b c*, and the line *a b c* may be considered as a lever of the first kind with arms of equal length, turning upon the central point or fulcrum *b*; *x* will therefore in all cases of motion, rise as much as *y* descends, and *vice versâ*, consequent, no power is gained in such a disposition, and hence the single pulley is frequently described as incapable of gaining mechanic power; but if instead of using it as in the last Figure it is reversed and permitted to move as at Fig. 39, then the case will be completely altered, for now if a weight *d* is hung underneath the pulley, it will upon the principles of the lever of the second kind (page 55,) strain each of the ends *e f* of the cord equally, *e* will therefore sustain one half of the weight, and *f* the other, and consequently, if *e* be tied to a hook, and the power or strength be applied to *f*, only one half of the weight *d* will be felt, and *f* will now move twice as far as *d* in the same time. It is however generally considered more advantageous to pull downwards than upwards, consequently in practice the two forms shewn at Figs. 38 and 39, are generally combined together, 39 being used to gain the power, and 38 to change the direction of the draught: this is effected by fixing the rope *e* either to the underside of the upper block, or to the hook which sustains it, while the rope *f* is made to join the upper rope *c y*, and terminates at *x* where the strength is to be applied, and accordingly Fig. 40 represents a pair of blocks so arranged.

If instead of employing two suspending ropes, as in the last case, three are made use of as in Fig. 41, viz. a rope tied to the top of the under-block at *g*, carried over the sheve *h*, under that at *i*, and over that at *k*, so as to terminate at *l*, where the power is to be applied, then a power of three will be gained, and so of any greater number of ropes for the theoretical power of pullies is that it is as the number of suspending ropes employed where the blocks are arranged one above the other, as in the two last Figures, on a supposition that every rope becomes equally strained or bears its proportionate part of the load, while the power is applied to one rope only, and therefore if a weight were suspended by such a set of pullies as would require 10 suspending ropes while one of these raised the weight, a power of 10 would be gained, or

100lbs. would be raised by 10lbs. of exertion. But the great friction attendant upon the pulley, the rigidity or want of flexibility of the cords, and the unequal quantities of motion these have in passing over the several sheves of a compound block abstract very materially from the power that would otherwise be gained, insomuch that it becomes almost impossible to make use of more than 6 ropes with advantage, for the ropes do not strain equally on account of their unequal velocity of motion, and the block will be thrown to one side if it contains many parallel sheves on the same axis, by which the whole side of each sheve is made to rub against the side of the block and much friction is produced. That this unequal motion of the rope and distribution of weight upon it must take place will be seen in contemplating Fig. 41, where it will be evident that if the end *l* of the cord is depressed 12 inches it will raise the block *g i* but 4 inches, because while this is ascending it is giving out a portion of the rope *o* over the sheve *h*, by which the rope *n* becomes prolonged and the ascent of *g i* is opposed, and in blocks containing a greater number of sheves than either of the foregoing examples the first pair of sheves will reduce the weight to one half, the next pair will divide that half or reduce it to one quarter, the next pair to one-eighth, and so on; thus producing a very unequal distribution of the weight over the block, which will cause it to hang on one side and produce the inconvenience above stated.

Mr. James White, with a view to remove these imperfections in the pulley, and to avoid lateral friction, obtained a patent for a system of pullies formed as at Fig. 42. Each block instead of containing separate sheves consists of a series of sheves turned out of one solid piece, but varying in size in arithmetical proportion, so that each series when viewed in profile or section appears like so many grooves cut on the surface of a very obtuse cone. Supposing that each cone contains six grooves this will admit of 12 suspending lines as in the Figure, and admitting each of these grooves to be separate sheves of equal diameter, as in common blocks, then since there are 12 lines, in order to bring the two blocks together, as much line must pass over the uppermost pulley as is equa to 12 times their distance asunder; but from inspection of the Figure it is evident that the second pulley cannot receive the full quantity of line by as much as is equal to the distance betwixt it and the first. In like manner the third pulley receives less than the first, by as much as is the distance between the first and third, and so on to the last, which receives only 1-twelfth of the whole; for this receives its share of line s from a fixed point in the upper frame which gives it nothing, while all the others receive the line, partly by turning to meet it, and partly by the line coming to meet them. The outermost pulley would therefore make 12 revolutions, while that which received the line s would make but one, and the intermediate times and velocities would be a series of arithmetical proportionals, of which if the first number were one the last would always be equal to the whole number of terms; it follows therefore that if the diameters of certain grooves in the same substance be exactly adapted to the above series (the line itself being supposed incapable of stretching and of no magnitude) the necessity of using several detached sheves in each frame or block will be obviated, and with that most of the inconveniences to which the pulley, as commonly constructed is liable. In practice the grooves cannot however be in true arithmetical proportion, for the diameter of the rope employed must be deducted from each term, without which the smaller grooves to which such diameter may bear a large proportion, would be too large and would introduce worse defects than this improved construction tends to obviate. Mr. Garnett proposed removing the friction attendant upon pullies by placing a number of small friction wheels or rollers round the hole in each sheve, so that the central pin instead of passing through a mere hole in the sheve would pass between these rollers. This was however not only found very expensive, but was liable to get out of order when great weights were raised, and consequently it has never been much used. A very considerable improvement was made in the pulley by Lieut. Shuldham, who adopts the conical form of Mr. White, but uses a double cone placed base to base but in one piece, and by thus using but one compound sheve with an axis fixed to itself, two large friction wheels can be admitted and are sufficient for each block. The rope is so reeved or passed through these blocks as to end in the center, consequently the friction is not only greatly diminished but likewise all tendency to run to one side; but as a double series of ropes must be used, proceeding from the outsides towards the center of the blocks, and the pull is made by two ropes instead of one (of course of smaller dimensions than those generally used) there may perhaps be more danger of entanglement than with common blocks. Lieutenant Shuldham's Improvements in Blocks will be found fully detailed in the Transactions of the Society for the Encouragement of Arts, Manufactures, &c. Vol. XXXIV. page 189, for the year 1816.

Mr. Smeaton in his account of the building of Eddystone Light House gives an account of the blocks he there used, which are very simple and good. The chief improvement consists in employing blocks with an odd number of sheves, and reeving them in such manner that the pulling line comes out over the central sheve of the block instead of at its side, and thus the tendency to run to the pulling side is prevented; the form of block shewn in the Plate at the upper part of Fig. 41, has the same object, for here the sheves are placed one under the other upon separate spindles instead of being by the side of each other on the same spindle, consequently the strain can only be in a downward direction, but if many sheves are used

62 to 71.

Fig. 35

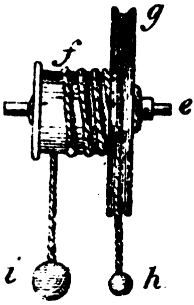
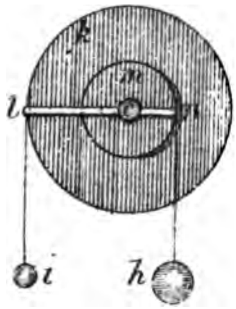


Fig. 36.



.44.

Fig.

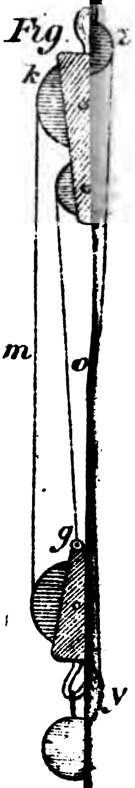


Fig 38.

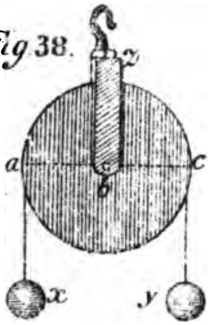


Fig. 40.

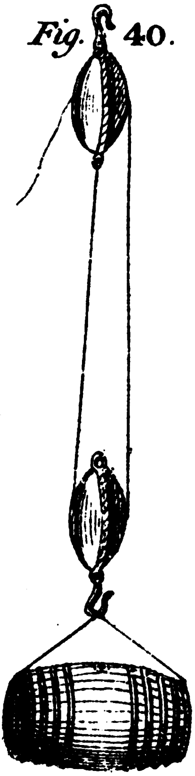
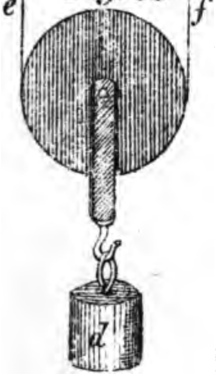


Fig. 39



in this way, the length of the blocks becomes so much increased, as to abstract very materially from the height to which a body may be lifted, otherwise this is a very good construction.

The arrangement of pullies, called Running Blocks gains great power, but is incapable of raising weights to considerable heights, it is shewn at Fig. 43, in which the weight *r* is hung to a single sheve. From what has been said (page 67) the rope at *s* will of course be strained by only half the weight of *r*; another single sheve is however applied at *s*, which reduces the weight at *t* to one quarter; a third sheve at *t* again reduces it to 1-eighth at *v*, which is in this case made the pulling rope by passing it over the fixed sheve *w*, but if more running sheves had been applied, each succeeding one would reduce the resistance to one-half of what it was before such application. Another very simple and useful form of running blocks is represented by Fig. 44, consisting of a pair of ordinary blocks *x y* of any number of sheves; the top block in this case instead of being immoveably fixed upon a hook as usual, is attached to the end of a single cord passing over the single fixed sheve *z*, and the opposite end of this cord is fastened to the top of the lower block; the consequence of this is that when force is applied to the pulling line *u* the top block *x* descends just as much as the bottom one *y* rises, and they meet each other half way; the same quantity of line is therefore drawn out as if *x* were a fixed block, while by its motion, *y* only ascends half the distance it otherwise would do, consequently by the laws of the mechanic powers as already stated whatever power *x* and *y* would gain by their number of sheves and lines if used in the ordinary manner, will be doubled by this arrangement.

THE INCLINED PLANE

Is the Fourth and next Mechanic Power. It is seldom introduced into the construction of machinery, and applies most particularly to the moving or raising of loads upon slopes or hills, as in rolling a cask up or down a sloping plank into or out of a cart or cellar, or drawing a carriage up a sloping road or hill, all which operations are performed with less exertion than would be required if the same load were lifted perpendicularly. The power thus gained by the inclined plane is as its perpendicular height is to the length of its inclining face or slope; thus if *a b* Fig. 45, Plate V. be a plane, sloping or inclining to the horizon or horizontal line *c b*, the line *a c* drawn perpendicularly to *c b*, and touching the top of the inclined plane at *a*, is its height, and as many times as the height *a c* is contained in the length of the sloping face or plane *a b* so much will be the power gained by such inclined plane.—In the present instance *a c* is contained twice in *a b*, therefore if a ball *d* be rolled from *b* to *a* it will have moved twice the length of *a c*, notwithstanding which its actual elevation is only from *c* to *a*, the consequence of which is that *d* may be drawn up *a b* with half the force that would be necessary to raise it in a perpendicular direction from *c* to *a*. The power of the inclined plane may be proved experimentally by passing a line from the waggon *f*, or other body to be moved, over a single pulley *e*, Fig. 46, and hanging a weight *g* at its opposite extremity; in this Figure the height of the slope is contained six times in its length, consequently if the waggon-model *f* weighs 6lbs. it will be balanced in any situation by 1lb. at *g*, and a very little additional weight will move it up the inclined plane. The power of inclined planes or hills may therefore in all cases be found by a simple rule of proportion, as for example. It is desired to know what force will balance a weight of 375lbs, upon an inclined plane, which rises 6 feet in 15 feet of its length? The proportion will stand thus—as 15 ft. : 6 ft. :: 375lbs. to a fourth term 150lbs. which when found will be the answer required. To calculate what force the above weight of 375lbs. will balance or support upon a similar inclined plane, the proportion must be reversed, thus as 6 ft. : 15 ft. :: 150lbs. to 375lbs. and from the proportion that holds good in all triangles of similar shape it matters not how small a portion of the hill or inclined plane be taken to examine its power provided its surface be an even plane, for the dotted line *h i* Fig. 45, will be the half of the length *i b*, in the same way that *a c* is half the length of the entire surface *a b*. Either a large or small portion of an inclined plane may therefore be taken to examine its power, provided the rise or elevation that occurs in that part *only* be taken into account, and this rise in actual hills is best ascertained by the levelling instrument, (see page 19.)

The above observations on the power of the inclined plane presume that it is quite smooth, and that bodies move upon it without friction or impediment which never can be the case in practice, even in the most perfect machines, consequently some allowance must be made from the calculated effect, and when carriages move upon rough or sandy roads, this allowance must be very considerable. The reason why horses are eased by taking a zigzag direction in ascending or descending a steep hill will appear from the foregoing account of the action of the inclined plane, because in this way the effective length of the inclining surface is increased while its height remains the same.

THE WEDGE

Is the Fifth Mechanical Power, and this like the last admits of but few applications to machinery. It is however a very simple and effective instrument, but one which does not admit of very accurate experimental proof of its power on account of the friction that attends its use. Motion by the wedge is generally produced by the blows of a hammer or heavy mallet, and in this way it is used for cleaving or splitting large blocks of wood or stone. The form of the wedge is shewn at Fig. 47, but its angular point may be increased or diminished in any degree, and although it may appear at first sight to be similar to a moveable inclined plane, yet it has this characteristic difference that the inclined plane is always considered as containing one right angled triangle, and the wedge has none, thus the back *a c* of the inclined plane, Fig. 45, is at right angles to its base *c b*, and this is the case in common with all inclined planes, but the back *k l* of the wedge, Fig. 47, does not make a right angle with either of its faces or sides *k m* or *l m*, but is at right angles to the central line as dotted from *n* to *m*, which line is equally distant from both the faces, and therefore the wedge may be considered as formed of two inclined planes placed base to base, for *k n m* is one inclined plane, and *l n m* is another, and the line *n m* is a base common to them both: *o p q* is a piece of wood into which the wedge is supposed to be driven for the purpose of splitting it. The power of the wedge is therefore estimated nearly in the same manner as that of the inclined plane, for when the wood does not cleave at any distance before the wedge there will be an equilibrium between the power impelling the wedge downwards and the resistance of the wood against its two sides, which is generally stated to be as half the thickness of the back is to the length of one of the sides, or as the line $n l$ is to the line $l m$. But when the wood splits, as it commonly does, before the wedge, as in the Figure where q shows the bottom of the cleft, then the power is reckoned as half the back is to the entire length of the cleft from its extreme point q to the top of the wedge $k l$, for $k q l$ now becomes the effective wedge instead of $k m l$. There is however a difference of opinion upon the means of computing the power of the wedge which is stated by some writers to be as the entire width of the back is to the conjoined length of both the sides, which is the same thing as taking one of the sides and comparing it with half the back; but others contend that its power is as the entire back $k l$ is to one of the sides $m l$ or $m k$, and all the instruments that are made for experimentally demonstrating the power of the wedge prove the truth of this last position, notwithstanding it is but seldom admitted; thus if the wedge $r s t$ Fig. 48 be supposed to weigh 12 ounces, and that its length from s to t is 12 inches, while its breadth from r to s is 6 inches, then half its back would be 3 inches, which would be contained four times in its side, and it ought therefore according to the generally received rule to gain a power of 4, or to lift 4 times its own weight. In the machine for showing the power of the wedge the resistance is always made by two rollers v and u, drawn towards the center and towards each other by the weights and lines w x, passing over pullies at y and z, and thus pulling in opposite directions, and accordingly if such a wedge as has been described did gain a power of 4 it ought to be in equilibrio, when the weights w ond x amount to 48 ounces, whereas it will be found to be so, when they are together 24 oz. or double the weight of the wedge which corresponds with the last rule, for the entire back $r s$ is double the face $s t$, and since the rollers v u would be in contact with each other before the introduction of the wedge, and can only be separated by it, to the distance of 6 inches (viz. the length *r s*) so this will be the amount of the joint elevation of the weights *w x* while the wedge descends 12 inches, being its entire height; the resistance therefore moves half as much as the power, and makes a coincidence between the motion produced by this and the other mechanic powers which would not take place if the power were as half the back is to the face. It has been demonstrated by some that the power of the wedge is as half the back is to the base or central line *n m* Fig. 47, instead of the face *l m*, but on account of the great friction that always attends the use of the wedge it is probable that no calculation comes near the truth, and in real practice all that can be said is, that the less the breadth of the back is in proportion to the length of the side, and the greater will be the advantage in the instrument. Besides this, by using a sufficiently acute angle, the wedge will by its friction maintain any opening it has made without danger of its closing again, and without continuing the effort that has produced the motion; on this account the wedge becomes particularly useful for raisng great loads to small heights, as in elevating ships in dry docks for repairs, and it is used in oil and other presses for maintaining the power which has been previously obtained. Knives, axes, adzes, and a variety of other tools for separating materials, act upon the principle of the wedge.

THE SCREW

Is the Sixth and last Mechanic Power, and is of great force, and very general application. When a screw is at liberty to move equally in all directions, it is simply called a Screw, but when it is confined at its ends so that it can merely revolve without advancing or withdrawing it is called an *Endless Screw*, and in this case it generally acts into the teeth of a wheel either to move or be moved by that wheel, but its power is alike in both cases. The screw, though a mechanical power, can hardly be called a simple instrument, because from its great friction it always requires the assistance of a lever to turn it, and when so turned its power is estimated by taking its circumference, and dividing this by the distance between any two of its threads. The reason of this mode of estimating the power of the screw is that it is in reality nothing more than an inclined plane formed round a cylinder instead of being a continued straight line. This may be seen by cutting a piece of paper into the shape of a very acute right angled triangle like the inclined plane Fig. 46, and wrapping it round a cylindrical ruler or pencil, as at Fig. 49, when the surface of the inclined plane will immediately form a screw. Taking the circumference of a screw is therefore but another manner of measuring the length of the inclined plane which wraps round it, and taking the distance between one thread and the next to it, is but measuring the rise of that inclined plane in such length, and from the properties of the inclined plane it follows, that the closer the threads of a screw are together, in proportion to its its diameter, and the greater the power that will be gained by it.

Almost all the varieties of presses in common use depend upon the screw for their action, while the endless screw is highly useful for communicating very slow motion to wheel-work; for the tooth of a wheel will only be advanced the distance between two threads of the screw in its entire revolution, unless indeed more inclined planes than one are purposely placed round the cylinder to produce more rapid motion, and then the screw called double, triple, &c. according to the number that may be employed. The screw is not only of importance for gaining great power, but likewise for producing very delicate and fine motions, and for measuring them; for when a screw is well made and works pleasantly it may be taken for granted that all its threads are equally distant from each other. If therefore the threads of a screw are so fine as not to admit of their being counted without difficulty, but it is found that turning the screw round 500 times advances its point an inch, which may be measured, it follows that the threads must be the 500th part of an inch asunder, and as the large head of a screw may be divided into 100 equal parts, so turning it round one of these divisions will advance its point but the 50,000th part of an inch. It is in this way that the screw *micrometers* are made which are attached to microscopes and telescopes for measuring very minute objects, but the screw is seldom made so fine as here mentioned. Astronomical and many other instruments for nice purposes are moved by screw adjustments, and the celebrated dividing instrument of Mr. Ramsden which is now so generally used, and by which the divisions of astronomical instruments are brought to their present perfection in this country owes its powers to the accurate and slow motion of the screw.

The wheel and axle, and the screw admit of having their power made almost infinite by very simple means, thus if *a b* Fig. 50, be supposed to represent a cylinder of equal dimensions from one end to the other, having the two ends of a line wound round it in opposite directions, while the central part of the line passes under the pulley *d* to which a weight is attached, it is evident that turning the cylinder *a b* round in either direction will produce no elevation or depression of the weight, because if the line be unwound from the end *a* it will be taken up with equal speed upon *b*, and *vice versâ*, but if one end of the roller be made larger than the other, as in the Fig. at *b*, then the line will wind upon or uncoil from *b* with greater speed than it can be taken up or given out by the end *a*, then the pulley and weight *d* must rise or fall whenever *a b* is turned, and as the most minute difference in the diameters of the ends *a* and *b* will produce this effect, so it will be seen that by varying them, any velocity may be given to *d* between not moving at all and moving with great rapidity.

The modification of the screw above alluded to is shewn at Fig. 51, and was first described by Mr. Hunter, in the Philosophical Transactions, Vol. 71—*e* is the bottom board of a common press, and *f* the moveable or pressing board urged or forced downwards by the screw *h* turning as usual in the top rail *g*. The screw *h* is however made hollow to receive another screw *i* which works into it, but is fixed in the board *f* in such a manner as to be incapable of turning round.—Now if the threads of the two screws *h* and *i* were of the same size it is evident that turning *h* would produce no motion in the board *f*, because the direction that would drive *h* downwards would screw *i* upwards into *h* in the same degree, and consequently *f* and *g* would preserve the same distance asunder, but if the thread upon *h* or *i* be one finer than the other, then one screw will descend faster than the other will ascend, and consequently *f* will move. The nearer the threads are alike the slower will be the motion, consequently the power of the screw can in this way be increased to any degree without the necessity of diminishing strength by the adoption of fine threads.

Notwithstanding the means of calculating the advantage gained by the use of the several mechanic powers has been given, yet in estimating the power of any complex machine which contains several of them, it is not necessary to use the rules that have been laid down for each of them individually, but on account of the relation that is at all times maintained between motion and power, the two extremes of such a machine may be compared with each other without regarding its intermediate construction, except so far as friction is concerned. The calculation of the powers of machinery becomes in this way much abridged and facilitated. Thus for example, if I have a crane for raising goods, containing a pair of blocks with several ropes, acted upon by two or three-toothed wheels and pinions, the last of which is moved by the application of a man's strength to a winch or handle that turns an endless screw acting into the last wheel, it is evident that such a machine contains the majority of the mechanic powers, and that the calculation of its power would be an operation of some length; for the power of the blocks must first be estimated, this would be multiplied by the advantage of the first-toothed wheel over the roller or cylinder upon which the rope winds, considered as a wheel and axle; the second or third-toothed wheels and pinions must be treated in the same way, then comes the screw, acted upon by the winch which is a lever of the first kind, and the power gained by these must be taken into the account. Instead however of doing all this, if the motion of the winch be immediately compared with that of the weight, without any regard to the parts of which the machine may be formed, its power will be equally well ascertained. Thus, if the winch is of such length that the circle it describes in turning round is 3 feet in diameter, then as the circumference of a circle may in round numbers be called three times its diameter,* so the distance the man's hands will pass through in every revolution will be 9 feet. The actual motion of the load during one revolution (or any given number of revolutions that may be taken for the sake of greater accuracy in the measurement) of the winch must then be taken, and the motion of the winch being divided by the motion of the load, the quotient will be the power of the machine. Thus, if the load rises one inch for each turn of the handle being equal to 9 feet, then since one inch is contained 108 times in 9 feet, the theoretical power of the machine will be 108, or it will lift 108 pounds with the exertion of 1 pound of power, and the winch will move with 108 times the velocity of the load.

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* The circumference of a circle is more than three times its diameter, and a very useful rule for general purposes, is to say the diameter is to the circumference as 113 is to 355. This is sufficiently correct for most practical purposes, and is very easily recollected, because the figures in the above proportion consist of two *ones*, two *threes*, and two *fives*, being the three first odd numbers, merely divided in the middle into two equal parcels of three each.

The power is here called *theoretical* because no machine is capable of acting up to its full power as given by calculation, on account of the constant existence of friction, as well as many other defects to which all machinery is liable, arising from the inflexibility of ropes and imperfections of workmanship. On this account it becomes necessary, in all cases, to make an allowance for the difference between the theoretical and actual performance of a machine, amounting in general to about one-third of the estimated power. This however must vary with circumstances, and of course admits of no calculation, but can only be experimentally ascertained.

The cause of friction is attributed to the irregularity of the surfaces of bodies which rub one upon the other; for the protuberances or projections of the one will fit or lock into the hollows and cavities of the other, and thus produce a resistance to motion; and it is probably on this account that dissimilar substances are found to rub together with less friction than occurs when similar materials are used. Experience proves that a piece of polished steel or iron will move upon a piece of polished brass with greater ease than when two such pieces of steel, iron, or brass are used together, and it is on this account that the iron or steel pivots of machinery are most frequently made to move in brass bearings. In the best watches the steel pivots of the wheels are made to turn in diamonds or rubies, by which their friction is still further diminished. The reason of this diminution of friction in dissimilar materials seems to arise from the minute projections and cavities in different substances, being dissimilar, and therefore not fitting each other. Thus, if *k* and *l* Fig. 52, represent two pieces of iron of the same kind, it may be reasonably supposed that whatever irregularities of surface exist in the one will equally exist in the other, and also, that they will have the same form and magnitude; if therefore an attempt is made to slide *k* over *l* the irregularities will fit each other, and occasion much friction or opposition to motion; but if one of the pieces of iron be preserved as at *n* Fig. 53, and another substance of a different texture such as brass or bell-metal be applied upon it, as at *m*, then if the irregularities are of such forms as not to admit of fitting into each other, or if they happen to fit each other in a less degree than before, the friction and difficulty of motion will be considerably diminished. Oil and grease have the property of diminishing friction when applied to metals, and soap or powdered blacklead do the same thing to wood-work, and this power in all probability arises from such materials stopping or filling up the inequalities, which, while they existed, produced the mischief. That such irregularities, as have been spoken of, do exist on all surfaces can be proved by examination of them with a microscope, but of course they exist in a much less degree than is shewn in the Figures; it is even sometimes found that too perfect a surface is productive of evil, for then the parts are brought into such close contact that the attraction of cohesion begins to operate.

Friction is of two kinds, viz. actual rubbing, or such as has been already spoken of, and friction by contact, which is also called friction of the second kind. A carriage, with its wheel locked or free to move, affords a very good example of both kinds of friction, for when the wheel is locked so as to prevent its turning round, the carriage cannot move without dragging the edge of the wheel upon the road and producing friction of the first kind; but so soon as the wheel is set at liberty it revolves, and every part of its edge comes successively in contact with the road, and then friction of the second kind is produced. In light machinery, that which would be friction of the first kind is very frequently changed into the second by the adoption of friction wheels or rollers. Thus to diminish the friction of the pulley over which the string passes in Attwood's Apparatus (see page 22) such an arrangement is made use of. It is shewn at Fig. 54, *o* being the large pulley which carries the string and its two weights, and *p* its axle or pivot. This pivot instead of moving in a hole of brass, lies in the hollow formed by the intersection of the two small brass wheels *q* and *r*, which revolve on seperate pivots, and are placed one a little behind the other, and rather less apart from center to center than their own diameter. The consequence of this is, that the friction becomes very much diminished, for while the large wheel *o* revolves in the direction of the arrow placed upon it, the four smaller wheels *q r*, and two similar ones on the other side of the wheel *o* (which are consequently invisible in this Figure) revolve in contrary directions. It may appear that four pivots are in this way brought into use instead of two, but since a wheel turning upon a pivot, is in fact a lever of the first kind, in which the radius of the wheel is the acting, and the radius of the pivot the resisting arm, of course the friction will be overcome by this mechanical power, and may consequently be diminished in a very considerable degree. This arrangement is the same that is alluded to in describing the blocks of Mr. Garnet and Lieut. Shuldham, at pages 69 and 70.

Friction of the first kind, it appears then affords great obstruction to the moving of bodies, while that of the second is of small importance on smooth roads, or where no impediments occur, provided the wheels or friction-rollers are properly formed to facilitate such motion. A cylinder, from its form, will move in a straight forward direction upon a plane, while a cone or a truncated portion of one will move in a circle.

This at once points out the proper form for wheels, notwithstanding which cylindrical wheels are seldom used, and our heaviest waggons are constantly built with conical ones. It is however evident that whenever a cone is constrained to move in a straight forward direction, or a cylinder is made to move in a circle, that great friction will be produced, and that which would otherwise be friction of the second kind is changed into that of the first. This arises from conical wheels having different diameters at their opposite sides. Thus, Fig. 55 is a profile of such wheels as are generally applied to broad wheel waggons, and in these, since the inside diameters *s t* are greater than the external ones *r r* and *r r*, it is impossible that the circle or edge of *s t* can revolve in the same time as that at *r r* because in friction by contact, every part of the revolving surface must come in succession into contact with the road or plane *w w*. That the wheels are moving under restraint will be evidently shewn by cutting one of them in half in the direction of the dotted line *w x*, when it will be seen that the half *r r* having the least diameter will revolve much quicker than the larger half *s t* whenever the wheels are moved along a table. The axle-trees must likewise be bent downwards to permit the conical surfaces *v t*, *t v* of the wheels to come into contact with the road, and if there may be advantages of strength derived from this mode of construction, still it must be confessed that the base upon which the carriage stands, or the distance from *r* to *r* is very much diminished, by which the liability to overturn is increased (page 45) while the effect of a cone moving straight forwards upon a road will be to grind the materials of which it is composed to powder. Drug mills generally consist of large and heavy cylindrical stones which are made to revolve upon their edges in very small circles round a center post: by this contrivance a grinding effect is produced, for a cylinder revolving in a circle acts in the same way as a cone moving in a

page 72 to 85.

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Fig. 45.

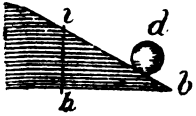
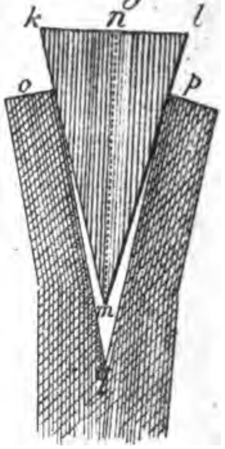


Fig. 47.



:9.

Fig. 52.

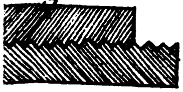
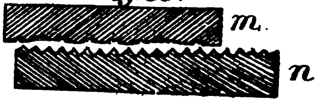
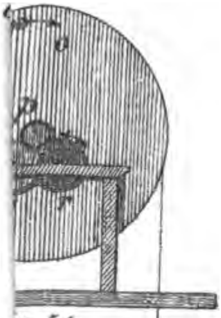


Fig. 53.





g.54

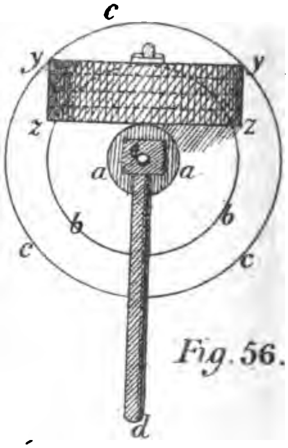


Fig. 56.

straight line.—Fig. 56, is the plan of a drug mill, *c c c* being the iron floor or platform on which the materials are placed to be ground, and *y y z z* the cylindric stone, that is made to revolve round the center *e* by the strength of a horse or other power applied at the end of the long lever *d*; the outer edge *y y* of the stone will describe the circle *b b*, and will of course have all its points brought in succession into contact with *b b*, while the inner face *z z* only describes the much smaller circle *a a*; but since *y y* and *z z* are equal, and revolve in the same time while *a* and *b* are very unequal, but are also passed over in the same time, it follows that great rubbing friction must be produced instead of mere friction by contact, and it is this rubbing that tears or grinds the materials more than the weight of the stone. If the stone *y y z z* were formed of a number of thinner stones as indicated by the dotted lines drawn across it, it would be found that each section would revolve with a different velocity, and that the mill would lose its power of grinding.

From a number of experiments that have been made to investigate the power of friction it appears to increase in a less ratio than that of the weight of the moving body, although this conclusion is contrary to the generally-received opinion, and has a limit, for if the moving surface be too small or too thin to support its own weight it will not bear evenly, and will wear into a groove or notch which may occasion much additional friction.

However perfectly a piece of machinery may be made, still friction to a certain degree must ever exist and cannot be prevented. It follows therefore that the power that is given to one extreme of a machine can never be conveyed without abatement to the other; and hence it will immediately appear that a perpetual motion is impossible, because this presumes that a certain power is to be communicated to a machine, and is to be transferred through all its different movements from the beginning to the end of the machine, when it must be given back again without diminution, in order that it may be communicated back again to the beginning of the machine to produce a repetition of the same impulse it had produced in the first instance, otherwise the motion of the machine could not be maintained. But since no effect can be produced that is greater than its cause, and as the cause must be diminished by friction, vis inertiæ, &c. in its transfer through a machine, so it cannot be renewed with a power equal to that with which it began, consequently a perpetual motion must be considered as an unattainable thing, inasmuch as it implies a renewal of power which no machine can give to itself.

It may at first sight appear that fly-wheels and springs assist the power of machinery, because a man will turn a machine equipped with a heavy fly-wheel for a much greater length of time than he could without it; and horses will draw a heavier load upon springs for a given time with less fatigue than in a carriage without them. It is however certain, that they have no such effect. A fly-wheel, it is true, will in many cases facilitate the motion of a machine, but it can only do so by virtue of its momentum or moving force, and since all motion implies a force to produce it, and its power can never exceed the amount of that force, so as much power must have been given to the fly-wheel to produce its motion, as it can possibly give back again. The great importance of the fly-wheel is derived from its receiving power at one moment, and giving it back at another when perhaps it is most wanted; thus a man moving a machine by turning a winch at nearly breast-height will have very different degrees of power in different parts of each revolution, for in turning it from its lowest situation upwards towards himself he will be able to exert an immense force in comparison to what he can do in turning it from its highest situation downwards and from him. In the first position he will therefore probably be able to exert much more force than the machine may require, while in the latter his strength may be scarcely sufficient, but if the machine has a fly-wheel, the superabundant force exerted in the first instance will not be thrown away, but will be converted into momentum in such fly, and will operate to assist him in the last position. The work will on this account be rendered equable and regular, and will consequently produce much less fatigue than if it were otherwise. A fly-wheel can therefore be looked upon in no other light than as a magazine or reservoir for superfluous power which it will regulate and distribute with equality, by virtue of its vis inertiæ and momentum. In this way it becomes of great use and importanee in the steam-engine, when applied to produce regular rotatory motion, for the power of the engine only exists while its piston is moving upwards and downwards, and is suspended while the change of direction takes place; but by using a fly-wheel, the momentum this acquires during the ascent or descent of the piston, maintains the regular motion of the machinery during the short period of suspension. (See Steam Engine, Section on Hydraulics.)

A spring, such for example as is used for producing motion in clocks or watches, requires a certain force to wind it up, or bend it for action, and it never can give back more force than has so been communicated to it. The reason why carriages upon springs move more easily than those without them is, that the wheels or carriage part are cut off from the body or load by such springs, and consequently, the vis inertiæ of the load prevents its partaking of all the motions that the inequalities of a road would produce. The wheels of a carriage must fall into all the cavities, and be raised over all the stones or other protuberances they pass over, and thus a part of the power of the horses must be thrown away to produce thus up and down, or perpendicular motion at the same time that it is moving forwards; but if springs intervene between the wheels and the load, than the perpendicular motions of the wheels can only be communicated to the load by their agency, and since a heavy mass of matter cannot be very suddenly put into motion on account of its vis inertiæ (4th Property of Matter, page 6,) so by the bending of the springs the greater part of the motions of the wheels will never be communicated at all to the body or load, and the resistance to its straight forward motion will thus be much diminished.

SECTION V.

PNEUMATICS,

OR

THE MECHANICAL PROPERTIES OF AIR.

THE Earth which we inhabit is entirely enveloped or surrounded by a thin, transparent, and invisible fluid called Air, the mechanical properties of which are considered under that branch of science called Pneumatics. This air together with the various gasses, steams, vapours, and exhalations that are constantly thrown into it, and which form clouds, is called by the general name of the Atmosphere. Atmospheric air is consequently of a very mixed nature, but when pure is found by chemical examination to consist of two permanently elastic gasses or airs, called nitrogen and oxigen, in the proportion of about 79 parts of the former to 21 of the latter by measure, or 77 and 23 parts by weight, and as the one or other kind of gas prevails, the air is more or less wholesome.

Air, although invisible, is material and partakes of all the properties which belong in common to other matter (page 4,) for it occupies space, and it attracts and is attracted, and consequently has weight. It likewise partakes of the nature of fluids, for it adapts itself to the form of the vessel which contains it, and it presses equally in all directions, consequently it must be considered as a material fluid; but inasmuch as it is highly elastic, a property which is common to all gasses, steams, and vapours, while the more visible and tangible fluids, such as water, oil, spirits, &c. possess this character in a very slight degree, if at all, so they require a separate examination, as already noticed at the commencement of Mechanics, page 12.

The various airs or the gasses are called permanently elastic, because under all changes which can be wrought upon them, they maintain their characters of fluidity and elasticity, and will not admit of being congealed or rendered solid; with steams and vapours the case is very different, for they arise from inelastic fluids, by the application of heat, and they are highly elastic so long as they retain their form of vapour, but upon being cooled they return again into their original state of inelastic fluid, and therefore differ very materially from air, and cannot be said to be permanently elastic. Water affords a very good instance, for this is inelastic, (see Hydrostatics), but its steam is elastic in the highest degree; whenever this steam becomes cooled it reverts back into its original state of water, and of course resumes all it former characters. Since air has weight, and every thing upon the earth is surrounded and enveloped by it, it follows that all things must be subject to its pressure which will be exerted, not only upon them, but upon itself, and since air is elastic or capable of yielding to pressure, so of course the lower part of the atmosphere will be more dense, or in a greater state of compression than that which is above. Suppose for example that the whole height of the atmosphere is divided into 100 equal parts, and that each of these may weigh an ounce, or may be equivalent to the production of that pressure, then the earth and all things upon its surface will be pressed with the whole 100 ounces, the lowest stratum of air will be pressed by the

99 ounces above it, the next by 98, and so on until we arrive at the 99th stratum from the bottom, which will of course be subject to no more than one ounce of pessure, or the weight of the last or highest stratum.

Springs of every kind expand or contract until they arrive at a state of equilibrium with the force that is acting upon them; this is very well illustrated in the spring steelyard, represented at Fig. 56, Plate VI. in which *a b* is a spring screwed upon the standard *c* at *a*, while its point *b* traverses over the graduated arch *d*. While the scale *e* is empty the point *b* will stand at the top of the arch, but on putting a weight into *e* the point will be depressed, as in the direction of the dotted line to *d*, and a greater weight would depress it still more, and the weight so put into *e* would thus be pointed out among the divisions upon *d*.

The air acts in the same way, for being of an elastic nature it will of course yield to any force that may be impressed upon it, until its spring becomes a balance to that force, and it is on this account alone that we are insensible of the air's pressure, for notwithstanding the body of a man of ordinary stature is calculated to sustain no less a pressure of air than 32400 lbs. yet the spring of the air contained within the body exactly balances or counteracts the pressure from without, and makes him insensible of the existence of any pressure at all; and the spring and pressure of air will thus balance each other in all cases except when the communication is cut off, and the natural equilibrium is destroyed by some disturbing cause.

The air pump is the instrument that is generally used for the destruction of this equilibrium, for by means of this machine the air may be taken from the interior of vessels which are put upon its plate, and then the effects of the external and undisturbed air immediately begin to show themselves.—Thus for example if a small glass receiver, which is open both above and below, be placed upon the plate of an air pump, and the palm of the hand is put upon it, so as to cover it completely without leaving any orifice for the admission of the external air, so soon as the pump is moved the hand will be forcibly held down to the receiver, and cannot be released again without difficulty; for the air which is within the glass being rarefied or diminished in quantity, that which is without will preponderate by its weight, which keeps the hand down, while the spring of that air that is contained within the hand will cause its lower side to swell, and enter the glass to a considerable depth. This is but another form of the experiment mentioned at page 6, viz. the bursting of a bladder tied over the top of an open receiver; for so soon as the spring of air is diminished by abstraction of its quantity, the weight of that which is without will have sufficient power to burst through a stretched piece of bladder, and in falling upon the pump plate will produce a very loud report.

This at once shows the necessity of having all glasses to be used upon the air pump with hemispherical or rounded tops, that they may present a dome or arched form to the pressure of the external air, and all such glasses are called by the general name of *receivers.* If an open-topped receiver of 6 inches diameter be covered with a piece of thin flat window-glass instead of a bladder, the pressure of the external air will break it; but this is a dangerous experiment, and ought to be tried with great caution on account of the violence with which the fragments will be driven in all directions; for the same reason great care must be taken not to break receivers while they are exhausted.

That the spring of air causes it to expand according to the amount of external pressure may be very well shewn by the following experiment. Take a bladder either with or without a stopcock attached to it, and press nearly the whole of the air out of it, then either shut the stopcock or tye up the orifice very closely with a strong waxed thread; in this state place it under a receiver upon the plate of an air pump and exhaust the air. The bladder will at first appear empty because the pressure of the outward air is an exact balance to the spring of that which is contained within. By the process of exhaustion the outward air becomes rarefied, and is no longer capable of opposing that spring. The bladder will therefore gradually expand, until at last when the receiver is pretty well exhausted, it will appear to be fully blown, and is sometimes even burst; but if the motion of the pump is stopped before this takes place, and the air is readmitted into the receiver by the cock for that purpose, the bladder will shrink down into its original dimensions, thus proving that no additional quantity of air was admitted into it, but that the spring of that which it previously contained produced the effect.—This experiment is sometimes varied by putting the bladder in a frame, and placing weights upon it, when it will not only expand, but will raise the weights at the same time.

If a small portion of the shell of an egg be broken away at the small end, and it is then placed under a receiver and exhausted, the bubble of air that is always contained at the large end, will in like manner expand, and in doing so, will force out the contents of the egg. A withered apple when treated in the same way will expand and appear fresh, provided its skin is not broken; and a small fountain, or *jet d'eau*, may be produced by filling a small glass globe half full of water, and screwing a tube into its neck, so that its lower end may project considerably below the surface of the water; the air above the water will in this way be confined, and of course when the apparatus is placed under a tall receiver and exhausted, that air will expand, and by pressing upon the surface of the water will force it up the tube, which must terminate in a small orifice to produce a jet.

It being thus proved that air is of an elastic nature, and to the top; but as soon as the air is returned into the receiver they are all instantly compressed and disappear. The weight of air has thus far been identified by its effects only, but it may likewise be shewn in the following manner. Take a glass flask, or bottle, containing an exact wine quart, and to the neck of this cement a brass cap, having a valve opening outwards upon it, and a screw by which it may be attached to the air-pump. Place this flask so fitted up in one of the scales of a nice beam, and balance it with weights put into the other scale; this done, remove it from the scale, screw it to the air-pump plate, and exhaust it as perfectly as possible, when upon placing it again in the scale it will be seen that the abstraction of its air makes it lighter, insomuch that it will becomes necessary to place about 15½ grain-weights in the scale with the flask to reproduce the balance that before existed, thus showing that a wine quart of air weighs on an average 15 grains and a half. This experiment was first tried by Mr. Hooke in 1664, but cannot be considered as a very accurate one, on account of the vacuum produced by the air-pump being imperfect, and the buoyancy of the external air tending to diminish the apparent weight of the flask, air is therefore really heavier than it appears to be from this experiment. And the very accurate investigations of Sir George Shuckburgh (Phil. Trans. Vol. LXVII. p. 560) show it to be 836 times lighter than pure water, when the barometer is at 29½, and Fahrenheit's thermometer at 53.

Since air possesses positive weight, it cannot be matter of surprise that it should be capable of producing pressure, and of holding receivers fast to the pump plate, whenever that air is removed from the interior of them, which would otherwise balance that pressure by its spring or elasticity, and since the pressure of fluids acts in all directions, it is of course unnecessary that the power should be applied in a perpendicular direction; if therefore a receiver be placed upon a small brass plate with a stopcock underneath it, and which is called a *Single Transfer Plate*, this may be screwed into the pump plate, and exhausted, and the stopcock then shut, when it may be removed from the air-pump, and still will be firmly fixed to the plate in all situations, for the plate will be as forcibly pressed against the receiver, as the receiver is against it, in whatever position it may be placed in, nor can they be separated from each other until the exhausted air is permitted to return by opening the cock.

This effect is beautifully illustrated by the Magdeburgh hemispheres, so called from the place where the experiment was first tried. They consist of two domes or hollow half-balls of brass, each having a ring on its outside large enough to admit the power of the hands to be applied for drawing them asunder. The hemispheres are made to fit upon each other by a ground joint, which is rendered air-tight by a little pomatum, and one handle removes in order that the globe which they form when they are placed together, may be screwed to the air-pump to be exhausted; the lower hemisphere likewise contains a valve or stopcock in its handle by which the return of air into them after they have been exhausted is prevented. On producing a vacuum within the hemispheres, and screwing on the handle, if they form a globe of 5 or 6 inches diameter, it will require a very strong man to pull them asunder, because the pressure of the atmosphere will amount to about 14 lbs. upon every square inch of surface in the ball. If therefore such a ball exposes but 10 square inches of surface, it will require 140 lbs. to separate them. The power with which these hemispheres are held together may be easily examined by attaching the lower handle to the floor or a table, and applying the hook of a steelyard, (page 53,) to the upper handle; and that they are retained together by no other force than atmospheric pressure, can be proved by hanging them after they are exhausted, in the interior of a receiver and then exhausting it, when the lower hemisphere will fall off by its own weight without any force being exerted upon it, because that which held it to the upper one, viz. the pressure of the external air has been removed by the exhaustion of the receiver. The Magdeburgh hemispheres were invented by Otto Guericke, and were first used at the breaking up of the Diet of Ratisbon in 1654. On this occasion they were made on so large and magnificent a scale as to require a team of 20 horses to pull them asunder.

To show that many of the effects vulgarly attributed to *Suction* depend on the weight and pressure of the atmosphere, and that no such principle as suction exists in nature, cover the air-pump plate with a piece of wet wash leather, and place a small receiver with a ground bottom upon it, but not over the hole in the pump plate, cover this again with a larger receiver that does extend over the hole, and upon beginning to work the pump, the last receiver will instantly be fixed or held down by pressure, while the internal one will remain at liberty, and will even be raised up and made to move slightly, because as the large receiver is exhausted, the spring of the air within the smaller one will cause it to expand, and it has no other way of doing so and escaping, but by raising up that which contains it. The small receiver remains at liberty because the air both within and without it is of the same density, and the external air which otherwise would hold it down, has been removed by the process of exhaustion; but the instant that air is again admitted under the large receiver, it will be set at liberty, and the small one will become fixed although it has never been over the hole in the pump-plate. This change cannot therefore arise from any suction produced by the pump, but is brought about solely by the pressure of the air when admitted, for by pressing upon the small glass it cannot get into the interior of it in the same way, as it was capable of getting out of it by expanding, and consequently the small glass becomes fixed to the pump-plate, and cannot be removed from it, but by sliding it gently along until it is brought over the hole, when the air will be readmitted. An almost similar effect, but in a different shape, may be shewn with an instrument called *A Double Transferrer*, the form of which is given at Fig. 57, Plate VI.—It consists of two small brass plates, ground flat on their upper surfaces, each of which has a stopcock underneath it at *h* and *i*, which are screwed into the tube *k k*, being close at both its ends, and this again has a third stopcock *l* in its central part for screwing into the pump-plate; if all the three cocks are open it is evident that when *l* is attached to the pump-plate, both the equal-sized receivers *f* and *g* may be exhausted at the same time, but presuming *h* only to be shut, then the receiver *g* will alone loose its air and become fixed, and in this state, if *l* be shut, the whole instrument may be unscrewed and removed from the pump without any change taking place in the state of the receivers, but so soon as the cock *h* is now opened, the glass *f* will become as firmly fixed to its plate as that at *g*, because *g* being void of air while *f* is full, so soon as a communication is opened between the two by the pipe and cocks *h k k i*, half the air that was in *f* will rush into *g* to produce an equilibrium, and consequently each of the glasses will become half exhausted, and if they are of the same diameters will be held to their respective plates with the same force or pressure, which will be brought into action upon the one as well as the other.

The common household pump, or that which is vulgarly and improperly called the Sucking Pump, affords another exemplification of the constant pressure of the air, for the water rises in this machine from no other cause than atmospheric pressure. Fig. 58 is a section of a pump of this kind, of which it is needless to give a very minute description, because what has already been said of the construction of the air-pump at page 94 will apply to this, and explain it: *m m* is the cylinder or barrel, *n* the air-tight piston which moves or works within it, by means of the piston rod *o*, moved by the lever *p p* or any other contrivance, *q* is the suction or feeding-pipe descending into the jar of water *r r*, which would be a well or other reservoir in an actual pump, *s* the valve at the bottom of the barrel covering the top of the feeding-pipe, and *t* the valve in the piston, both which valves open upwards, *u u* is an open-topped received for supporting the pump above the jar of water *r r*.[*] Raising the piston *n* from the bottom to the top of the barrel will produce a vacuum in the barrel between *n* and *s*, and the pressure of the air upon the surface of the water at *r r* will force a quantity of that water up *q*, through the valve *s*, into the interior of the barrel where it will be retained, because it cannot pass back again through *s*; when the piston *n* is lowered it will pass through the water previously raised by means of its valve *t*, and will thus get to the bottom of the barrel. On raising the piston a second time the water which has so passed through it, will be carried up by it into the cistern *o*, from whence it will be discharged by the spout *v*, while a new vacuum is forming between *w* and *s*, which will of course be supplied as before with water, and thus it will appear that the common water-pump is rather a Pneumatic, than an Hydraulic machine.

To prove however that the action of this pump depends upon the formation of a vacuum and the air's pressure, take the whole apparatus as before described, and place it upon the plate of an air-pump, so that the large supporting receiver *u u* may be exhausted, and then it will be found that working the handle *p p* will not raise water, for now the air that otherwise would press upon the water in *r r*, to drive it up the pipe *q* being removed, the water will not rise at all. A pump of this kind therefore not only affords evidence of the existence of atmospheric pressure, but it also shows the amount of it; for if the pipe *q* be continued to about 40 feet perpendicular from the bottom of the pump before it touches the water, working the pump will never raise the water higher in that pipe than to 32 or 33 feet, so that it cannot be made to rise into the barrel of the pump, and consequently will not be delivered from the spout *v*. It is thus ascertained that a column of water 33 feet in height, is a balance in weight to the utmost pressure of the air, and as this is subject to diminution in a manner that will be presently explained, so at times the air's pressure, will not raise 28 feet of water, and consequently a pump on this construction ought never to be placed at a greater height from the water it has to raise than about 25 feet otherwise it will not work with certainty. The diameter of the column of water is of no consequence in this case, because whatever it may be, an equal sized column of air will always act against it (See *Hydrostatic Paradox* in Hydrostatics); but supposing the column of water to be one inch square, then in a height of 33 feet it will contain 396 cubic inches which will weigh 14lbs. and about 1-third, and consequently it will be superior to the action of atmospheric pressure, as stated at page 97, when speaking of the Magdeburgh hemispheres.

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[*] It was thought unnecessary to give a separate representation of the air-pump, on account of its external appearance being well known, and its internal construction agreeing so nearly with this figure. The suction pipe *s q* would communicate with the hole in the pump-plate, if this were an air, instead of a water-pump.

This balance of power between a perpendicular column of water and atmospheric pressure, was first observed by Gallileo in erecting a pump for the Grand Duke of Tuscany, but he does not appear to have been aware of its cause. This was first investigated by Torricelli who made use of quicksilver, a fluid 14 times as heavy as water in his experiments, by which he was enabled to produce a pressure equal to that of water with 1-fourteenth part of the height, and accordingly his experiments were very neat and accurate. He filled glass tubes of different sizes and which had one of their ends closed, with quicksilver, and then by covering the open end, he inverted them, into basins filled with the same metal, and thus he found that the diameters of the tubes had no effect on the experiments, but that all those that were less than 28 inches in length or height remained full of quicksilver when inverted, and that in all those which were longer (whatever might be their length) the quicksilver descended until it became stationary at between 28 and 31 inches from the surface of that which was in the basin, thus leaving an empty space at the upper end of the tube, which has since been found to be the most perfect vacuum producable by art, and which is in compliment to its discoverer called the *Torricillian Vacuum*.

A tube filled with quicksilver and thus disposed is called a *Barometer*, because the column of quicksilver being maintained by the pressure of the air, must of course be a balance to that pressure, and if the amount of pressure changes as it is found to do, then the height of the mercurial column will change also. It is on this account that the quicksilver in the barometer moves up and down through a space of 3 inches, because the density of the air is never so great as to cause it to sustain the quicksilver at more than 31 inches from the surface of that in the basin below, nor does it ever diminish so as to let the column descend lower than 28 inches. The figures 28, 29, 30, and 31, which are placed on the scale of every barometer, are therefore to indicate the height of the mercurial column, reckoned from the surface of the quicksilver which is in the basin or leather bag at the bottom of the tube, and they ought to be attended to, rather than the words Stormy, Rain, Change, Fair, Set Fair, &c. and which really are of very little use; for it is the rising and falling of the quicksilver that predict changes of the weather, rather than any situation or height at which it may stand at a certain time. To use a barometer with advantage, its scale ought not to be placed higher than the eye of the observer, but he should rather look downwards than otherwise at the quicksilver. Having observed where it stands upon approaching the instrument, the tube should be gently shaken by tapping it with the back of the finger when the quicksilver will either rise or fall, and thus show which way it would have moved, had it been left undisturbed; if it rises fine weather may be expected, and the contrary if it falls, particularly if its motion be slow, and continues in the same direction for several days together. When large motions take place very suddenly and the quicksilver is unstable, violent winds may be expected. The concave or convex surface of the quicksilver will also indicate whether it is rising or falling, the latter only taking place where it is in the act of rising, and by due attention to the motions of the quicksilver the barometer will be found a highly useful instrument for predicting all changes in the weather.*

Such observations as these had been made by Torrecelli, but it was left for the great genius of Blaize Pascal to explain their cause, as well as to point out another most important application of the barometer, namely its use in measuring considerable heights or elevations, a purpose to which it is now very commonly applied with great success.

Pascal as well as Torrecelli had suspected that the quicksilver was maintained in the tube by the pressure of the air, but he was afraid to broach such an opinion on account of its novelty, and the disputations into which he well knew it would lead him; he therefore resolved upon putting the matter to the test of experiment in a manner which from its novelty and ingenuity must ever reflect the greatest credit upon him. His reasoning upon the subject was of this nature—if the quicksilver is maintained in the barometer tube by the pressure of the air. that pressure ought to be greater at the surface of the earth, than at a considerable height above it, and accordingly he thought that if two barometers agreed in the height of their quicksilver when they were close together upon the ground, and one of them was to be removed to a great height in the air, that which was elevated would have a shorter column of air to press upon its quicksilver, and accordingly it should descend. This important experiment was tried in 1648, upon the Puy de Domme, a mountain 3565 English feet in height, near Clermont in France, with the most complete success, for the two barometers when together stood at 28, while that which was taken up the mountain fell about 3½ inches and stood at 24.7. In his descent he observed the mercurial column proportionably increase, and on returning to the bottom again, they once more agreed.

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* For farther particulars of the manner of observing the barometer with this view, see a small pamphlet on the subject by Mr. Jones, Optician, Holborn Hill.

That the quicksilver is maintained in the barometer tube by atmospheric pressure alone, can be very satisfactorily proved by the air-pump. For this purpose take a barometer tube 32 inches long, and fill it with quicksilver by means of a small funnel, invert it in a little bason of the same metal, and set it upon an air-pump plate, cover the whole with a tall narrow receiver, and as the process of exhaustion proceeds the quicksilver will descend in the tube, at first with great rapidity, but its velocity will diminish as the vacuum becomes more perfect. On readmitting the air, the quicksilver will again rise until it arrives at the spot where it stood before the action of the air-pump had commenced.

Such an instrument therefore becomes *a guage* for the air-pump, to ascertain the degree of rarefaction or the perfection of the vacuum it produces, and accordingly a barometer is always used for this purpose. The full length of tube is applied to such pumps as stand upon the ground, but for table air-pumps very short barometers are used, because a guage is of no use when the process of exhaustion commences, and only becomes important when it is nearly completed, or when the quicksilver is within an inch or two of being brought down; a guage therefore of four inches high is quite sufficient, and this is generally made in the form of an inverted syphon, as shewn at Fig. 59. There is no basin in this case, but the leg *a* is quite filled with mercury, and it extends a little way up *b*, which has an immediate connection with the receiver to be exhausted: as the mercury in *a* descends that in *b* rises, and as the height of the column must be reckoned from the surface of that in *b*, so of course when the mercury in both legs is level or at the same height it must be considered as quite down, and from the construction of the *Syphon Guage*, as this instrument is called, every half-inch of motion in the quicksilver will be equivalent to a whole inch in a straight barometer from the one portion of quicksilver rising just as much as the other falls. In the choice of a barometer, that which has the largest tube and most capacious basin for the mercury will be the best, because a large tube prevents capillary attraction (p. 9) from acting, and by a large basin the small quantity of mercury discharged out of the tube does not materially alter the point from which the scale is made, and therefore it will be more correct. The rise and fall of the mercury being confined to a space of three inches, contrivances have been formed to augment this distance into a more enlarged scale. The principal of these are the Diagonal Barometer, which was invented by Morland and Ramazzini, but is not very common, and the Wheel Barometer by Dr. Hooke.

In constructing barometers the quicksilver ought to be very pure, or free from amalgamation with other metals, and to be cleared of oxide or dross as well as from air. If it is otherwise it will adhere to the glass. It may be very well cleared from dross and dirt by filtering it through the pores of close wood, and this at the same time affords a beautiful experiment; for this purpose take a cup having a plug of hazle or other hard wood put into the lower part of it, in the direction of its grain, place this upon an open-topped receiver on the plate of an air-pump, and put a saucer under it to receive the mercury. As soon as the pump is worked, the pressure of the external air will drive the mercury through the pores of the wood in a most beautiful shower of quicksilver, and it will be perfectly cleansed. Care must be taken to prevent any of the quicksilver from getting into the air-pump, as it would unite with the solder of the joints and destroy them; to render the mercury free from air, it must be exposed to a strong heat, which is called boiling it, and this should be done in the tube of every well-made barometer.

When the barometer is used for measuring the heights of mountains or other elevations, the temperature of the mercury must be considered as well as its elevation, because it will expand and contract with heat and cold, and the upper regions of the atmosphere are much colder than those below. The general principles of these kind of measurements it is hoped will be understood from the following explanation. When the barometer on the surface of the earth stands at 30 inches, and the temperature is 32 Fahrenheit, it has been ascertained by trial that taking such barometer to the perpendicular height of 87 feet just lowers the quicksilver 1-tenth of an inch, or will cause it to fall to 29.9; but presuming it to be raised still higher in the air or until it descends another tenth of an inch, or stands at 29.8, it is required to know how much it has been elevated? The second stratum of air is evidently equal in weight to the first, because each has produced an equal depression of the quicksilver, but since from the nature of the atmosphere as explained at page 90, each succeeding stratum is lighter or less dense as we ascend, so the second stratum, to be of equal weight, must be of greater height than the first, and consequently the whole ascent must be more than twice 87 feet. To examine this difference the density of the first stratum of air may be represented by the number of tenths of an inch of mercury which it is capable of supporting, and as the column was supposed to be at 30 inches high, this will be 300; for the same reason the density of the second stratum will be represented by 299, but the weights of these two strata are equal, therefore their bulks must be inversely as their densities, and since their bases are equal, difference of bulk can only arise from difference of height, and consequently to obtain the thickness of the second stratum of air, or its height above the first, it will only be necessary to say 299 is to 300, as 87 feet, the height of the first stratum, is to 87.29 feet, which will be the height of the second, so that the whole distance ascended will be 174.29 feet. In like manner if the barometer is carried upwards until the mercury falls to 29.8, then the proportion will be 298 : 300 :: 87 ft. : 87.584, or it will have ascended to the height of 261 feet and 7-eighths.

The above must not be considered as an accurate mode of proceeding, but is merely introduced to show the rationale of the process, and will answer pretty correctly for such elevations as do not produce a material change of temperature. The nicer kind of operations are more intricate and require great care. Barometers are made for the express purpose of measuring elevations, and for this purpose accurate thermometers are attached to them, and they have their scales divided accordingly, and they are called *Mountain Barometers.* One of the best instruments for this purpose was invented by Sir H. Englefield, and a very simple and accurate method of using them will be found in the Notes to Professor Leslie's Elements of Geometry, p. 492.

By means of calculations corroborated by the barometer at different heights, it is ascertained that air at 3½ miles from the earth has but half the density of that upon its surface, and that it looses half its last density at about every succeeding 3½ miles; therefore taking the density of the air at the earth's surface as 1, at the height of 3½ miles it will be twice as rare; at the height of 7 miles it will be 4 times as rare, at 21 miles it will be 64 times rarer, and 4096 times at 42 miles. By the same rule at 49 miles high, it will be 16384 times rarer, and as this far exceeds the rarefaction that can be produced by the best air-pump, it is generally considered that the sensible atmosphere of the earth extends to the distance of about 45 miles from its surface.

The changes that take place in the atmosphere as indicated by the barometer appear to be influenced chiefly by three causes, viz. by the attraction that exists between air and certain fluids, through which a mutual mixture or incorporation takes place, as in evaporation. By change of temperature which affects the density of the air; and by motion produced by different causes, which also tends to vary its density and other characters.

It has already been stated in the opening of the present section, page 89, that the atmosphere consists not only of air, but of the various steams, gasses, and exhalations, that are constantly thrown up into it. Thus a wet cloth exposed to the air soon becomes dry, and water will gradually evaporate, or in other words it will be absorbed or taken up by the air that is in contact with it, and the water becomes mixed with that air, and is held in suspension or solution by it. It has been proved by experiment that a cubic foot of air is capable of retaining 12 grains of water in this way, consequently the atmosphere must at all times be more or less charged with aqueous vapours, and Dr. Halley calculated that 5280 millions of tuns of water were evaporated from the surface of the Mediterranean sea in one summer's day. Dr. Thompson says that 94450 cubic miles of water circulate annually through the atmosphere. So soon however as the density of air is diminished, or the particles of water are brought into a closer state of aggregation by cold or other causes they collapse and are precipitated, or returned back again in the form of visible fluid.

That water is at all times contained in air is evident from the cloud of vapour which we constantly observe is precipitated whenever a very clean receiver is exhausted upon the air-pump, and which is neither more nor less than a shower of rain in miniature. The damp on our walls and windows which precedes wet weather proceeds from the same cause, for then the air is over charged with water and begins to return a part of it. The presence of water in the atmosphere is detected by those instruments called *Hygrometers*, which are for the purpose of measuring the moisture of the air. They are of various forms, and are constructed of different materials, but unfortunately most of them loose their action in process of time. One of the simplest of these instruments may be formed of a considerable length of well-twisted flaxen string suspended from the ceiling of a room about 4 inches from the wall, and stretched tight by a leaden ball, above which is fixed a circle of pasteboard with divisions upon the edge of it, and a fixed mark on the wall for observing their motions.—In wet weather the string twists tighter, and of course turns the circle round, and in dry weather it uncoils.—The toy called the Weather-house is constructed on this principle—in this by the twisting and untwisting of the string the woman comes out in fine weather, and the man when it is wet. The most common hygrometer, which somewhat resembles a watch in shape, and is very frequently fitted up in the same frame with a barometer, is made with the beard of a peculiar species of wild oat, originally from Africa, but which grows in this country, and which possesses the curious property of coiling up in dry weather, and unfolding when wet: a scale beam with any substance capable of absorbing moisture such as a piece of sponge, of cork, or a quantity of unsized paper at one end, counterpoized by a metal weight at the other, becomes an hygrometer, since such substances will absorb moisture from the air, and become dry again, by which they are alternately heavier or lighter than the counterpoizing weight. Hygrometers are also made of whale-bone, and ivory cut across the grain, of quills, &c. but one of the best is made with a long strip of yellow deal wood, cut the transverse way of the grain, which by expanding and contracting gives motion to an index, as shewn at Fig. 60, *a b* being the piece of deal, *c d* the index, and *e f* the paper-scale over which it moves. Unfortunately no material has yet been found, nor any scale been formed which can be considered as standard, consequently no hygrometer will measure the moisture that is contained in any given portion of water, nor can the scales of any two of them be made to agree, therefore the hygrometer must be considered as an instrument of curiosity rather than of use. The ingenious instrument lately invented by Mr. Daniel* appears to be the only one which promises to be a standard and useful hygrometer, and should it prove as good in practice as it appears to be, it must be considered as a valuable acquisition to the apparatus for observing atmospheric phenomena.

Air not only incorporates with water, but with a great variety of other volatile materials by which many of its characters become much changed; and since heat assists in these combinations, so all warm or hot fluids will evaporate more readily than such as are cold. Drop a few drops of ether into a large drinking-glass, and cover it with a plate for a few minutes, when the ether will evaporate into the air, and will render it so inflammable that it will take fire on the approach of a taper. Exhaust an open-topped receiver, previously covered with a brass-plate having a stopcock, and a long bent copper-pipe attached to it, and let the air in again by this pipe through the flame of a lamp trimmed with spirits of turpentine. The receiver will appear to be full of smoak, but that smoak will have carried such a quantity of essential oil with it, and this will have so effectually combined with the air as to render it inflammable, and it will burn with a beautiful flame.

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* Quarterly Journal of Science and the Arts, edited at the Royal Institution, Vol. VIII. page 298. Jan. 1820.

Notwithstanding the attraction that thus appears to exist between air and various fluids, yet the very pressure of the atmosphere prevents their rising in vapour, or evaporating upon slight increments of temperature. Thus ether is the rarest of all the visible fluids, and when a cup containing a little of this is placed under the receiver of an air-pump, a very trifling action of the pump will make it boil. Water in the open air will not boil unless heated to 212 degrees, but when the atmospheric pressure is removed it boils at a much lower temperature; and a glass of strong ale when heated in the slightest degree will put on the appearance of boiling under an exhausted receiver.

These circumstances suggested to the Rev. Mr. Wollaston a means of measuring mountains or other elevations by means of the thermometer and boiling water, instead of using the barometer as mentioned at p. 106. For if water under atmospheric pressure at the surface of the earth requires its temperature to be raised to 212 degrees to make it boil, and it boils at a lower heat when that pressure is diminished by the air-pump, so boiling the water at a greater height in the open air, will diminish that pressure as effectually as placing it under an exhausted receiver, and accordingly it has been ascertained that water boils at the top of Mont Blanc at 187 instead of 212 degrees.

The moisture which is carried into the atmosphere when it gets to a considerable height assumes the appearance of clouds, for these are principally aqueous vapours floating in the air, having a sufficient degree of density to render them visible, but not so close a state of aggregation as to produce water. This has been amply proved by those who have passed through clouds, in ascending high mountains, as well as by the ascent of balloons; the form and state of the cloud will be materially influenced by the strength or violence of the wind as well as by the electrical state of the atmosphere.

Whenever such a change takes place in the atmosphere as will diminish its density, it will be less capable of supporting the quicksilver in the barometer which will of course descend, and when it is least capable of supporting the quicksilver, it will also be least capable of supporting aqueous vapours, clouds, and every thing else that may be floating in it: of course they descend, and if the clouds come into a sufficiently close aggregation to form drops, rain will be the consequence if in summer, or snow if in winter. This accounts for one of the uses of the barometer as a meteorological instrument, and shows at once why bad weather ought to be expected when the quicksilver falls, and the contrary when it rises. *Rain*, it therefore appears, is nothing more than a return of that water which has previously been evaporated, and since mountains attract the clouds towards them in pursuance of their attractive force (page 19); so sudden showers occur more frequently in mountainous countries than in others, and as the upper regions of the air are constantly so cold as to permit perpetual snow to exist on high mountains, so for the same reason if the water be raised ~~to a sufficient~~ height to become frozen it will be returned to the earth as *hail*, even in summer, while *snow* appears to be drops of water frozen at a much less elevation, for if this were not the case it could not preserve those regular and delicate cristalline forms which it is generally found to possess. Two of the most common flakes of snow are shewn at Fig. 61. Several others may be seen by reference to the Philosophical Transactions, No. 92, and they may be very well observed by catching snow upon a piece of black cloth, or a hat, and examining it immediately with a magnifying glass which need not possess great power.

A *Fog* is a cloud lying upon the surface of the earth, and consists generally of aqueous vapour mixed with smoke, but which is too dense and heavy to be carried up into the air: and *Dew* was till lately considered to be the condensation of aqueous vapour which had previously been evaporated; but Dr. Wells, with great ingenuity, appears to have ascertained that dew does not fall, as is generally supposed, but is occasioned by the recondensation of vapours arising from the earth at the moment of their ascent; for since the earth is warmed in the day time to a sufficient degree to produce evaporation, and is a slow conductor of heat, so it will retain its warmth much longer than the air in contact with it, and even after that air has been so cooled by the absence of the sun as to render it incapable of taking up the vapours that may be thrown into it, the consequence of which is, that they are immediately re-converted into that moisture called Dew, and which always makes its appearance at the setting of the sun.

The attraction that exists between water and air is reciprocal, in consequence of which air will always be found combined with water and other fluids in the same way as they combine with air. If a glass of water is placed under the receiver of an air-pump and that is exhausted, the air contained in the water will immediately become manifest, because its spring will cause it to expand, and the water will appear filled with small globules of air which, as they increase in size by diminishing the pressure, will rise to the top of the fluid and escape. If air is condensed upon the surface of water, a greater quantity of it will be taken up and absorbed, than under atmospheric pressure alone, and as different degrees of attraction exist between several of the gasses and water, so if carbonic acid gass, or Fixed Air as it was formerly called, is condensed and confined with water, an effervescing fluid similar to seltzer or soda water will be produced. Bottled beer, sparkling champaigne, and other similar liquors derive this property from their generating carbonic acid gass after they are bottled, and as the gass cannot escape, it combines with the liquor.

The condensation of air in an artificial way is effected by a pump or syringe called a *Condensing Syringe*, which is exactly similar in construction to the barrel of an air-pump, except that its valves open and act in a contrary direction. Thus in Fig. 58, if the valve *s* at the bottom of the barrel, and that at *t* in the piston, be supposed to open downwards, instead of upwards as in that figure, upon drawing the piston upwards, the interior space *n s* of the barrel will become supplied by air through the piston, instead of through the valve *s*; and on pushing the piston down again, since that air cannot return through *t*, it will be driven through *s*, and will be conveyed by the pipe *q* into any vessel or receiver that may be placed to receive it, and thus may air be condensed to any extent that may be required.

A simpler form of a condensing syringe, and that which is most commonly used is shewn in section at Fig. 62, in which *w w* is the hollow cylinder or barrel, and *x* the piston working in it by means of a piston rod and handle. This piston has no valve in it but is solid, and the only valve in the instrument opens outwards and is placed at the bottom of the barrel as at *y*. A hole is made at *z* for the admission of the air. Whenever *x* is drawn upwards it will therefore cause a vacuum or rarefaction in *w w* until it passes the hole *z* when the air will rush in and fill the barrel, but on lowering *x* it will very soon pass the hole *z*, when all the air that thus becomes confined in *w w* must be protruded through the valve *y* and cannot return again.

From the highly elastic nature of air, there is no limit to its condensation which may be continued so long as there is power to work the syringe, and sufficient strength in the receiver to resist the elasticity which increases with the degree of condensation. It has been carried to a great extent, but from all the experiments that have been tried, it does not appear that condensation produces any effect on the fluidity, transparency, or other characters of air. In making experiments upon condensed air, care must be taken to have the glass or other receivers of sufficient strength and thickness, because the pressure is not limited to 14lbs. upon the square inch, nor can the arched-form of a vessel be made use of as with the air-pump, (page 92) on account of the force being from within, instead of its being external.

The process of condensing air, and its increased spring when condensed, are very well exhibited by an instrument called the Condensed Air Fountain, shewn at Fig. 63. It consists of a hollow globe *g g* (which should be of strong glass to show the effect) mounted upon a stand or foot *h*, and having a brass cap *i* strongly cemented on to its open neck; the globe is half filled with water, after which the stopcock *k*, having an open tube *l* reaching very nearly to the bottom of the globe, is screwed into the cap *i*; in this state a condensing syringe is screwed to the upper part of the cock *k*, and when this is worked with the stopcock *k* open, the whole air which it throws in will be seen rising in bubbles through the water from the bottom of the pipe *l*, and it will be deposited in the upper half of the globe. When a sufficient condensation has thus been produced the cock must be shut, the syringe is to be removed, and the small adjutage or spouting pipe *m* screwed in its place, when upon opening the cock *k*, a fountain will be produced, playing to a height proportionate to the degree of condensation, and continuing either until all the water is exhausted, or until the air within the globe becomes of the same rarity as that without, which can only occur when the condensation has been carried to a very trifling extent.

This fountain derives its importance from its affording a very good example of the nature and action of those air vessels which are applied to various pumps for producing a forcible, equable, and constant discharge of water, as in the engine for extinguishing fires; it will therefore be referred to again in the Section on Hydraulics.

The *Air-Gun* is the best example of the surprising force which air is capable of exerting when condensed to a considerable degree, for by means of this instrument bullets may be propelled with a force very nearly equal to that of gunpowder. It is a curious fact, that although the air-pump is a modern invention, yet the air-gun, which is so nearly allied to it in the construction of its valves and condensing syringe, should have existed long antecedant to it; for it is recorded that an air-gun was made for Henry IV. by Marin, of Lisieux in Normandy, as early as 1408; and another was preserved in the armoury at Schmetau, bearing the date 1474. The air-gun of the present day is however very different from that which was formerly made, and which discharged but one bullet after a long and tedious process of condensation, while it now discharges five or six without any visible variation of force, and will even act upon a dozen, but with less effect. The general form of an air gun as now constructed is very similar to that of fowling-pieces, except that the lock has no flint, and that a strong iron or copper ball is fixed under the gun to contain the condensed air. The essential parts of this gun are shewn in section at Fig. 64, from which their uses and operations will be understood: *n* is the barrel of the gun, and *o* the air-ball screwed to the lower part of it; this ball has a conical metal valve *p*, opening inwards placed within it, and kept to its bearing by a spring; *q* is the hammer of the lock, which being cocked falls in the usual way upon pulling the trigger, and in falling it gives a blow to the steel-pin *r* which moves in an air-tight manner through a collar of leathers, and thus the value *p* is opened, and a quantity of condensed air admitted through a passage left for that purpose to the back of the bullet, which of course will be expelled. It must be observed, that the hammer *q* is so adjusted that if it is slowly let down it will not quite touch the pin *r*, and consequently the valve will not be opened, but when it falls by pulling the trigger the violence of the blow causes it to spring or bend a little, and thus a very momentary opening of the valve takes place, which is not sufficient to let the whole air escape, and by this contrivance a single charging of the ball is sufficient for the discharge of several bullets, while if it were otherwise arranged the whole air would escape at once. It requires considerable force, and time to charge the ball of an air-gun, and Fig. 65 shews the apparatus by which this is generally effected, *s* representing the ball removed from the gun, and screwed upon the top of a strong iron syringe *x*, formed like Fig. 62, but with handles *t t* on its opposite sides; the piston rod *v* is fixed to an iron cross *w w*, upon which the feet of the operator are placed, and the whole syringe and ball *x* and *s* are moved upwards and downwards by the handles *t t*, until the spring of the air condensed into the ball affords a very effectual resistance. The air-vessel *o* is sometimes formed by using two barrels one within the other, in which case the air is condensed into the space between them. The condensing syringe is also occasionally placed in the butt of the gun instead of being detached, and in some of the older guns a chamber was made for holding ten or a dozen bullets which dropped in succession into the barrel, in which case the instrument was called a Magazine Air-Gun, for a description of which see any of the Cyclopædias.

When the air of the atmosphere is thrown into motion by any cause, it produces the sensation called *Wind*, and although many circumstances may induce such motion, yet change of temperature is one of the principal of them. For since all bodies expand by heat (page 14), and have their particles set at a greater distance from each other, so heated air must be bulk for bulk lighter than that which is cold, and will consequently ascend in the atmosphere by virtue of its greater buoyancy. Smoke ascends in chimneys merely from its admixture with heated air, and the Fire-balloon which was the first kind of balloon ever constructed, and which was made on so large a scale in France, by Mongolfier, as to be capable of raising a man to a great height in the air, ascends merely because the air within it is so heated by the fire below as to produce a difference of density sufficient to overcome the weight of the machine with its load. Artificial winds on a small scale may be observed every day, in the currents and draughts of air that occur in our houses, for if a current of air is made to pass up a chimney by means of a fire in a room, the deficiency will be made good by fresh air blowing in through every crevice, and if these be stopped, the chimney will smoke for want of a supply of air; the hottest air will likewise be found at the top of every inhabited room, and the coldest at the bottom of it, consequently the gallery in a theatre is always much hotter than the pit, and since heated air will continue to ascend so long as it has an opportunity of doing so: it will generally be found on opening the door of a heated room that the flame of a candle placed near the top of that door will be blown outwards, while another candle upon the floor will be blown inwards, thus showing that two opposite currents of wind exist at the same time in the same place, for while the heated air is escaping at the top of the door, a supply of cold air is entering at the bottom.

The *sea* and *land-breezes*, which occur in the islands of the torrid zone, are but an enlargement of the same effect, and afford a very satisfactory explanation of the manner in which winds may be occasioned by a change of temperature in the air. In these, during the hottest part of the day, the wind sets in from all quarters, and appears to be blowing towards the center of the island, while in the night it changes its direction and blows from the center of the land towards the sea; for since the sun's rays produce much more heat by their reflection from land than they do from water, that portion of air which lies over the land will soon become heated and will ascend; a rarefaction and diminution of the quantity of air over the central part of the land will thus be occasioned which must be supplied from the sides; but as the land cools again in the night time, that portion of air which had been previously heaped up will begin to descend again, and by spreading and equalizing itself will producc a breeze blowing from towards the center.

The Trade Winds, so called from the advantage which their certainty affords to trading vessels, are another example of the same kind. They blow all the year round from east to west over the equator, and are occasioned by the rarefaction of the air by the sun's heat, and the motion of the earth from west to east; for since the equatorial regions of the earth are most heated, and any one spot which is so heated will by this motion be carried eastward, and other places to the westward will in like manner begin to be heated in their turn, while those further eastward by having passed the sun will become rapidly cooled, so the cold air from the east will move westward to supply the rarefaction which is there constantly forming, and will thus produce that perpetual easterly wind which the trade wind is known to be. When the sun has northern declination, or shines to the north of the equator, the trade winds shift to the north likewise, and they move towards the south as he approaches the southern tropic. They are found in the Pacific, or Great Western Ocean, in the Atlantic Ocean and the Ethiopic Sea, but from the position of the land and mountains bounding the eastern ocean they blow in a different direction, and change that direction twice a year. In this situation they are called *Monsoons*, and from April to September they blow from S E towards N W, and from October to April from N W to S E, for while the sun passes through the six northern signs of the Ecliptic, the various countries of Arabia, Persia, India, and China, become so heated as to cause the wind to blow towards them, while during the other six months the sun is south of the Equator, and the wind blows from them. There are several varieties of monsoons occuring in different parts of the equatorial regions of the earth, but which all appear to be reducible to the same or similar causes, which were first assigned to them by Dr. Halley.

Among the irregular winds, or those which are not constant but accidental, the *Whirlwind*, the *Harmatan*, and the *Sirocco*, may be mentioned as the most conspicuous. The first of these is occasioned by the meeting of two or more currents of wind from opposite directions, and which can only be occasioned by some temporary but violent disturbance of equilibrium. The Harmatan is met with on the western coast of Africa, and is generally attended by great heat and fog; it appears to be occasioned by a conflict between the heated sands of Africa, and the regular direction of the trade winds over that continent, and by disturbing their progress, it is frequently a forerunner of an hurricane in the West Indies. The Sirocco occurs in Egypt, the Mediterranean, and in Greece, and is chiefly characterized by its very unhealthy qualities. The air by passing over the heated sands of Egypt becomes so dried and rarefied as to be scarcely fit for respiration, and being so prepared, it absorbs so much humidity on passing the Mediterranean sea as to form a suffocating and oppressive kind of fog.

The force of wind or air in motion is ascertained by means of instruments called *Anemescopes* and *Anemometers*, and is as the squares of its velocities. Some of the sensible effects of wind, as given by Mr. Smeaton from Mr. Rouse's calculations, (Phil. Trans. Vol. LI.) are as follows:—When it moves at the rate of one mile in an hour its effects are scarcely perceptible; between 4 and 5 miles an hour produces what is generally called a breeze; from 10 to 15 miles an hour makes a brisk gale; from 30 to 45 miles, a strong or hard gale; from 50 to 60 miles, a storm; and from 80 to 100 miles in an hour produces an hurricane, such as occasionally occurs in the West Indies, and which sweeps away houses, trees, and every thing opposed to its force. For further particulars respecting the nature and force of winds, the reader is referred to Dr. Halley's excellent Papers on the subject in the Phil. Transactions, and to those of Mr. Smeaton (1759), and Mr. Edgeworth in the same work, Vol. LXXIII. and to Chevalier Borda's Paper (Mem. Acad. Scien. 1763.) As a practical rule Mr. Smeaton states on the authority of his friend Mr. Rouse, that the square of the velocity of any wind being found and multiplied by 16, the product will be the impulse or resistance upon a square foot in grain weights.

SECTION VI.

ACOUSTICS.

THE production and propagation of sound are treated of by the science called Acoustics, and although this may at first sight appear to be completely distinct and separate from Pneumatics, yet when it is considered that the sensation of sound is in almost every case communicated to the ears through the medium of air, that many sounds are produced by the air itself, and that they are all more or less modified by passing through it, such a connection must appear as will entitle it to be considered at least as a supplement to that science.

Sound is the result of certain motions or vibrations produced in sonorous bodies which vibrations are communicated to the air, and from thence to the ear, in a manner which will be afterwards explained, and of course the most distinct and audible sounds will be produced by those bodies which are so elastic as to admit of their being put into vibratory motion, and the more rapid the vibrations, the more acute will the sound be which is produced by them. Thus a ball of damp clay, which possesses no elasticity, will produce no other sound when struck, but that which arises from the condensation of the small portion of air between the clay and the hammer which strikes it. A hollow ball of brass will produce more sound because it is elastic, but still very little effect will arise from this, because a ball is the worst form for admitting of vibration on account of its forming an arch or dome in every direction, so that one part stiffens and sustains the other, but if such a ball be divided, and the edge of one of the hemispheres be struck, a loud, clear, and distinct tone will be produced, because an hemisphere will admit of the exertion of elasticity, or of momentary change of figure which is condusive to the perfection of sound, and accordingly the bells used for clocks and for musical purposes, have a nearly hemispherical form. The report of fire-arms, the smacking of a whip, the clapping of hands, and even thunder, are in like manner produced by sudden impulses communicated to the air, and transmitted to the ear by a succession of pulsations or vibrations induced in that air, but air cannot be considered as the only conductor of sound since all dry and elastic bodies will also convey it, though in a less perfect and rapid manner, thus the slightest scratch with a pin upon one end of a long piece of timber will be distinctly heard on applying the ear to its opposite extremity. It is generally believed that sound is conveyed through air by a succession of pulsations or concentric vibrations similar to those which are produced on the surface of smooth water by throwing a pebble into it; the sounding body will of course be in the center, and the waves or pulsations will diminish in strength as they recede from that center, until at last they become too weak to produce any effect on the auditory nerves. In this way sound is said to travel through the air, and is found to move in an equable and uniform manner, passing through spaces proportional to the times, at the average rate of 1142 feet in a second. That sound is progressive and moves with this velocity may be easily determined, for on observing a woodman cutting down a tree at a small distance, the stroke of his axe will be seen at the moment he makes it on account of the immense velocity with which light travels (see commencement of Section on Optics;) but the noise of the blow will not reach the ear until sometime after the stroke has been made, the period varying in proportion to the distance. To ascertain the velocity of sound with precision a person must be stationed on a spot and desired to fire a pistol upon a signal, the observer must measure off once, twice, thrice, or any given number of times 1142 feet upon a level plane, and having stationed himself at one of these distances he must be provided with a stop-watch, or what is better, a pendulum vibrating seconds, (page 30) which may be borrowed for the purpose from a common clock, and the instant he sees the flash of the pistol, he must observe the watch, or make the pendulum swing when it will be found that as many seconds will elapse between the flash and his hearing the report, as are equal to the number of times 1142 feet that he stations himself from the pistol. There appears to have been a little difference of opinion as to the velocity with which sound travels, since the Hon. Mr. Boyle made it 1200 feet, the Royal Academy at Paris 1172 feet, the Academy at Florence 1148 feet; but Sir Isaac Newton, Mr. Flamstead, Dr. Halley, and the Rev. Dr. Derham, all agree in making it 1142 feet. No person has perhaps pursued this subject with greater diligence, assiduity, and accuracy, or had better opportunities of doing so, than the last gentleman named, who not only varied his experiments as to distance, but as to the means of producing the sound, and he found that whether it proceeded from large guns, pistols, or the blows of hammers, &c. the sound occupied the same time in passing through the same space, and that he could ascertain the distances of places from each other by the motion of sound (taking it at the rate of one mile for every 9¼ half seconds) with as much precision as by trigonometrical measurement.

The velocity of sound, as transmitted through the air is however slightly influenced by the strength and direction of the wind, in a degree which was also accurately determined by Dr. Derham. The distance used on this occasion by him was nearly 13 miles, and he found that when the wind blew rather briskly in the exact direction of the sound, it was brought to him in 111 half sounds, but when it blew directly against the sound its passage occupied from 120 to 122 half seconds, a transverse wind did not however appear to affect the progress of the sound in the slightest degree. From a knowledge of the velocity with which sound travels, the distance of a thunder-cloud, or of a gun fired on board ship at sea, even in the night time, may be very accurately deduced; in the first case, the period of time between seeing the lightening and hearing the thunder must be taken, and if a stop-watch or pendulum are not at hand, the pulse may be used, for the pulsations of an healthy adult approach so near to seconds, that in the time of 4 or 5 of them no very sensible error can arise. That all substances do not convey sound with the same rapidity and facility as air, may be proved by placing the ear against a long dry brick-wall, and causing a person at a considerable distance to strike it *once* with a hammer, when the sound will be heard *twice*, because the air will convey it with greater rapidity than the wall, though each will bring it to the ear.

Sound, like light, decreases as the squares of the distance increase, and it is capable of reflection, consequently if it strikes against any elastic body of sufficient magnitude to turn it out of its course an *Echo* will be produced, for echoes are nothing more than reflected sounds; a considerable extent of smooth wall produces them in great perfection, and since all sounds appear to come from the place where they are produced, or from the point from whence they are reflected, so the apparent direction of a sound becomes completely changed by an echo. The laws by which the reflection of sound are governed are precisely similar to those of reflected light, (see Section on Optics), consequently the direction only of sound will be changed by falling on a plane surface, while it will be concentrated, or brought to a focus by falling upon one that is concave, and dilated or spread and weakened by one that is convex. Several acoustic recreations and deceptions depend upon these circumstances. Thus the whispering-gallery at the foot of the dome of St. Paul's Cathedral, which is a hollow hemisphere, produces an echo which concentrates, and thereby magnifies sound in a manner that will be understood by inspecting Fig. 66, in which M shews the situation of the mouth of the speaker, and E that of the ear of the hearer. Now since sound radiates in all directions, a part of it will proceed directly from M to E, while other rays of it will proceed from M to *u*, and from M to *z*, &c.; but the ray that impinges upon *u* will be reflected to E, while that which first touches *z* will be reflected to *y*, and from thence to E, and so of all intermediate rays which are not introduced into the figure to avoid confusion. The sound at E will therefore be much stronger than if it had proceeded immediately from M, without the assistance of the dome, for then the rays at *z* and *u* would have proceeded in straight lines, and consequently could never have arrived at the point E. The stone recesses on the opposite sides of Westminster-bridge, being semi-domes, produce a similar effect, for if a person whispers in the focus of one of them, he will be distinctly heard by another stationed in the focus of the opposite one. Two inanimate busts may be made to appear to hold a conversation by placing them in the foci of two large concave mirrors made of pasteboard, and placed opposite to each other, for a whisper uttered to the one will appear to proceed from the other by the reflection of the sound.*

Echoes are produced in every room, by the reverberation of sound from their walls, but on account of the velocity with which it travels they are imperceptible in small chambers, because the sound occupies no sensible period of time in moving from the mouth to the walls, and in returning back to the ear again, consequently the original sound and its echo become so blended and incorporated, as to appear but one sound; as the dimensions of the apartment increase, the defect will increase with it, and in buildings for music, or public speaking, it is often highly detrimental and difficult of prevention. Breaking the surface, or rendering it uneven by mouldings, and ornaments appears to be the most effectual method of checking sound and preventing echoes, and as wool and sawdust are both very bad conductors of sound, so carpeting or moreen or other woollen hangings or furniture will destroy the effect of a music-room; and an echo from a hollow partition or ceiling will frequently be diminished, if not destroyed, by laying sawdust behind it.

In order to produce a distinct echo of one syllable, or of a single sound, the reflecting obstacle must be at least 70 feet from the sound, so that it may have to pass through a distance of 70 feet to get to the reflector, and 70 more to return to the ear, making a total passage of 140 feet, which it will accomplish in rather less than 1-eighth of a second after the sound has been made, a period of time so small, that if it were diminished it is evident the echo must be assimilated with the sound itself. For an echo to repeat three syllables, the sound must travel 1000 feet, or the reflector must be situated at a distance of 500 feet.

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* For particulars of the manner of performing this experiment, see Hooper's Rational Recreations, Vol. II. page 220, or Encyclop. Britannica, article Acoustics; in both of which works many Acoustic Recreations are described.

Since sound radiates in all directions, it follows, that if that radiation is prevented by confining it in tubes, it may be carried to a great distance with very little diminution of its effect, and hence the use and application of those tin speaking-pipes, which are now so commonly used for conveying intelligence from one part of a house to another. That celebrated experiment the Invisible Girl, which excited so much curiosity in London about the year 1806, consisted merely of one of these speaking-pipes, made to terminate in a concealed manner in the exhibition-room, and so constructed as to throw its sound into the large ends of some speaking-trumpets placed to receive it, and which had the effect of reflecting the sound, and producing an artificial echo, by which its apparent direction was so changed as to give it the semblance of proceeding from the interior of the ball to which the trumpets were attached.*

The speaking-trumpet has also the property of conveying sound to a great distance, by preventing its radiation, and causing it to move in the direction of the axis or central line of the instrument. It produces this effect by reflecting the sounds that impinge upon its sides into this line. It has been contended by some, that the form produced by the revolution f that curve called a Parabola about its axis is the best, and that the mouth should be placed in the focus of it; but experience shews that the logarithmetical, or logistical curve is better, and it is accordingly the one that is always used. Fig. 67 shows something like the form of this curve, the con-

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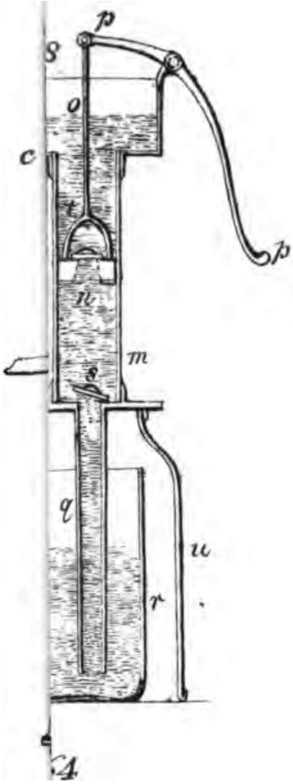
* The only account that has been published of this experiment is in Nicholson's Journal of Nat. Phil. &c. Octavo Series, Vol. XVI. page 69—a plate and detailed account is there given of it.

page 91 to 129.



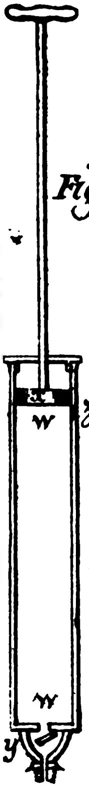


Fig. 62

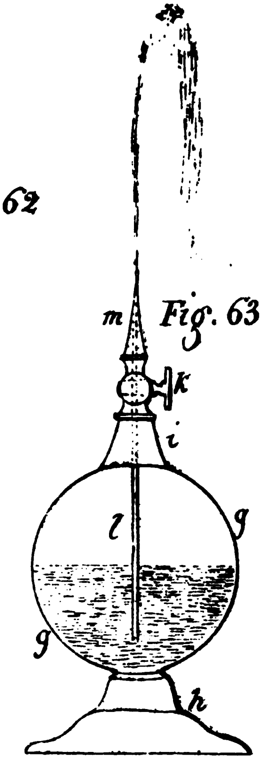
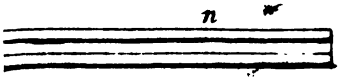


Fig. 63



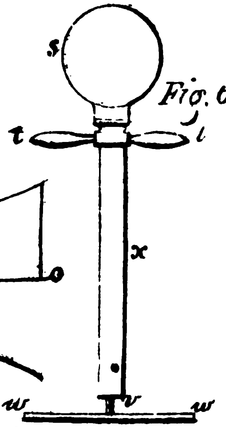
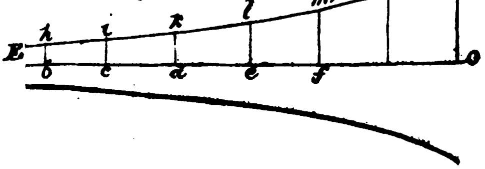


Fig. 65

Fig. 67



struction of which is that *n o* being the axis, if the distances *a b c d e* and *f* be equal to each other, then also must *a g* : *b h* :: *b h* : *c i* :: *c i* : *d k*, and so on. This form of trumpet not only transmits but receives sound with equal facility, and is therefore the best form for hearing as well as speaking; in proof of this if two such trumpets are placed opposite to each other in the exact direction of their common axis, the slightest whisper uttered into one will be distinctly heard by applying the ear to the other, even though the distance of a long room should intervene between them.

The manner in which the sensation of hearing, and the distinction of one sound from another is brought about, appears to be involved in the same darkness that attends all other delicate physiological investigations, all that can be known being the mechanical construction and operation of the ear which is briefly described as follows: The external ear, which is immoveable in the human species, is from its general form admirably calculated for receiving the tremulous rays of sound from all directions, and conveying them to the interior cavity where they are to produce their action upon the nerves. In animals the formation is different, and is more particularly adapted for receiving sounds in one particular direction at a time, but the external ear is moveable, in order that it may be set to the position from which the sound proceeds; the office is however alike in both cases, being to collect the sound and convey it into a tube passing through the scull, in the interior of which the organs of hearing are situated. This tube is called the *Meatus Auditorius*, and is terminated by what is called the Drum of the Ear, or *Membrana Tympani*, being a fine thin membrane resembling a tambourine extending obliquely across the meatus, and completely closing it. To the back or internal part of this membrane the handle part of a little bone called the *Malleus* or hammer is applied, the head of which is moveable in a bony sinus on one part, and on the other it is articulated with another little bone called the *Incus* or anvil, which freely moves in that articulation, and on the other end it is again articulated with a very small orbicular bone, the *os orbiculare*, and with the *stapes* or stirrop, which on its base is connected to a membrane spread over the *Foramen ovale*, or elliptic hole of another bony cavity called the *Vestibulum* or vestibule; this is again connected by five openings with three hollow loops of bony substance called the Semicircular Canals. The lesser part of the vestibule opens into another organ of very curious construction, which appears to have an important office to perform in the process of hearing; this is called the *Cochlea*, and in shape it much resembles the shell of a snail, it being of bone, and forming a cavity which makes 2½ revolutions from the base to the apex of an obtuse cone of bone which is in its center. The spiral duct thus formed is divided by a transverse *septum*, or partition of a triangular shape, being thick and bony next to the central cone, and diminishing at its outside into a membranaceous nervous texture, so that the upper and lower passages of this duct have no connection with each other, but the upper one opens into the vestibule, and the foramen ovale before-mentioned would open into the lower one, were it not closed by the thin membrane to which the stapes is attached. The auditory nerve enters the vestibule by several small holes and forms a curious lining, as well to it as to the semicircular canals and the cochlea, which it passes into when it spreads between the two membranes which form the septum or division above noticed, and after passing to its thin edge it divides in an exquisitely fine manner, and thus becomes the more immediate organ of hearing. These several cavities are filled with a white limpid fluid, upon the alternate but minute compression and dilatation of which the sense of hearing seems to depend. For the waves of sounds upon entering the meatus or external passage are first intercepted by the tympanum, to the membrane or parchment of which they communicate a vibratory motion, which will thus be also given to the malleus which lies in contact with that membrane, and since the malleus and incus are levers connected together, their motion will be communicated through the os orbiculare to the stapes which acts the part of a piston, and moves in the foramen ovale of the vestibule in an air and water-tight manner, because instead of being detached it is fixed to the central part of the membrane covering the foramen ovale, which is again attached at its margin to the bony part of the vestibule; any motion therefore that the stapes may have will tend to compress or dilate the fluid within the vestibule, semicircular canals, and cochlea, and thus cause it to press with varying force upon the fine and minute nerves with which these members are lined. The vestibule likewise sends down a tube, towards the hinder part of the mouth, called the *Eustachian Tube*, which is supposed to assist hearing, by receiving those rays of sound which may enter the mouth. It appears therefore that all sensations of sound are the effects of mechanical action or motion produced on the tympanum, and consequently if this becomes lax, from the effects of cold it will be incapable of vibrating, and deafness must ensue.*

As to the qualifications of bodies to produce sound, freedom of vibration, and contact with such elastic matter as will conduct sound are quite essential. Thus if a glass or a small bell are struck and made to produce sound, and the finger is then laid upon them, their sounds will immediately cease, because their vibrations will be stopped, and hence the use of dampers in piano-fortes and other musical instruments; but the hand pressed upon a large church bell while vibrating, will not materially affect its tone, because the vibrations of so large a mass of matter will produce sufficient momentum to resist any small pressure. Suspend a bell under the receiver of an air-pump in such manner that it can be rung without contact with the receiver, its covering plate, or the plate of the air-pump, and while the air remains in it, the sound of the bell will be distinctly heard; but on exhausting the air, the tone of the bell will be so far lost as to be scarcely audible. This experiment not only shows air to be a conductor of sound, but at the same time proves that some elastic body must be in contact with the sonorous one, for if the bell touches the glass or brasswork, they will conduct its sound to the external air and it will be heard.

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* A Map or Diagram of the Ear, exhibiting all these various parts on a large scale with accuracy, may be had of the Publishers of this Work, and of other Medical Booksellers.

The vibrations of bodies are regulated by laws very similar to those of the pendulum (page 29), consequently large bodies will vibrate much more slowly than small ones, and the slower the vibration the deeper will be the tone. It is on this account that the strings of musical instruments are made of different lengths and thicknesses, for if two strings of equal magnitude, but with their lengths as 2 to 1, are equally stretched, their vibrations will be in the same ratio, therefore the shortest will make two vibrations, while the longest makes one; again if two strings of equal length, but of unequal thickness, so that their respective quantities of matter are as 2 to 1, be equally stretched, then their vibrations will be as before; and the bass strings in most instruments have fine wire twisted round them to increase their matter, otherwise greater length must be resorted to for the production of similar tones. Again if strings are used of equal matter and length, their vibrations will be inversely as the square roots of the powers that stretch them. This stretching is generally brought about by screw-pegs, but in experiments weights must be used, and if two such strings are stretched, one by a 4 lbs. weight, and the other by 16 lbs., then the square root of 4 being 2, and that of 16 being 4, the vibrations of the strings will be as 2 to 4. which is the same thing as 1 to 2, and consequently they will agree with all the above cases.

Whenever two or more bodies are made to sound together their vibrations will coincide at certain intervals, and the shorter the intervals, the more agreeable will be the effect upon the ear; this coincidence is called a *Concord*, and when the vibrations are equal that concord is called a Unison. If the vibrations are as 2 to 1 as in the above cases, then every second vibration of the short or tight string will accord with the first of the long one, and the next perfect concord will be produced, called a *Diapason* or *Octave*. When the vibrations are as 2 to 3 the coincidence will be at every third vibration of the quickest, which therefore is the next degree of perfection, and is called a *Diapente* or *Fifth*; while the vibration of 3 to 4 will produce the *Diatessaron* or *Fourth*; but this, and the next, which follow in order, are not so agreeable to the judicious ear, and are therefore called *Imperfect Concords*. From a knowledge of the proportion that thus exists between the vibrations of strings and the tones they produce, the singular effect called *Harmonics* may be produced on stringed instruments; thus an open string gives one tone, but by gently pressing it in the middle, an octave to its first note will immediately be produced, by touching it 1-third from either end, a fifth, &c. all which effects are produced by nature, even without the formation of these artificial stops or bridges, for if a long string is put into vibration, and attentively listened to, its third, fifth, and octave may generally be perceived as well as its perfect sound. This is very well illustrated by that instrument called the *Eolian Harp*, in which if all the strings are tuned in unison with each other before it is exposed to a draft of wind, a wild and beautiful variety of sounds will be produced from the natural divisions that will take place in the vibrations of the strings.

The waves of sound produced by any sonorous body have a wonderful power over all other bodies capable of emitting the same sound, and will actually throw them into a state of vibration at a very considerable distance. This is called *The Sympathy of Sound.* To prove its effects strain two common harp, or violin, strings across two bridges upon one side of a room, and placé a single string prepared in the same way on its opposite side; tune the two first strings to two distinct or different notes, and place a small piece of paper over the center of one of them, to show by its motion when vibration takes place; on striking the other string it will be seen that no motion is produced, for the paper will remain stationary; but upon tuning the third or distant string to be in unison or even in octave to either of the two first which has the paper upon it, that paper will be instantly thrown off, by the violence of vibration that will be produced by sounding it, notwithstanding the distance of the strings from each other. This experiment may be equally well performed by a harp, or any other stringed instrument, and accounts for the responses that are constantly made by such instruments when in tune, to every noise or sound that is made near them.

A sympathy not only exists between similar sounds, but there appears to be some analogy between the musical notes and light, for as light is divisible into the seven primitive colours—Red, Orange, Yellow, Green, Blue, Indigo, and Violet, in the proportion of 11 of the first, 8 of the second, 14 of the third, 17 of the fourth and fifth, 11 of the sixth, and 22 of the seventh, (see Section on Optics;) so if any string is divided into two equal parts, and either half is again subdivided into 100 equal parts, it will be found to give the natural scale of notes by applying a bridge at corresponding situations, thus the whole string will sound some one note, and by applying the bridge at the eleventh division from the end, it will sound the next note above the first; removing the bridge 8 divisions further will produce the next note; 14 divisions more will give the next, and so on, until the bridge is removed to the center which will give the octave higher to the first sound. The doctrine of musical sounds is however so curious, and of such vast extent, that it is impossible to do justice to the subject in the limits of this publication; the reader is therefore referred to Newton's Principia; Helsham's Lectures; Martin's Philos. Britannica, Vol. II.; Smith's Harmonics; d'Lambert on Music, &c. &c.

SECTION VII.

HYDROSTATICS.

THE Science of Hydrostatics has for its object the examination of the mechanical laws which regulate the motions, pressure, gravitation, and equilibrium of inelastic fluids, as well as their effects upon bodies which float upon, or are immersed in them; while the construction of the various pumps and machines for raising and conveying water, and of machinery, to be moved by it, or which is to work in it, is made a separate branch of the same enquiry, under the name of HYDRAULICS, which will be the subject of the next Section.

The incompressibility of water had been long suspected, but was first fairly put to the test in the Academy del Cimento at Florence, as far back as 1650. A quantity of pure water was introduced by the academicians into a hollow sphere of gold, as being the most dense and compact metal, and a screw working in a water-tight joint, was then forced into the globe among the water, by which it was compressed with great force, and it was found that the water rather than admit of this compression actually ouzed through the pores of the metal, and appeared like dew on the outside of the globe.

This experiment is generally called the Florentine Experiment from the place where it originated.

Mr. Canton afterwards repeated this experiment in a very accurate manner, and with some variation of form. He inclosed a quantity of mercury in a glass tube, similar to those used for thermometers but of greater dimensions, and he observed to what point the mercury rose, when the whole was heated to 50 degrees Fahrenheit; after this the mercury by increased heat was made to expand until the whole tube was filled, and in this state its end was hermetically sealed,* and the instrument was again cooled down to 50 degrees. The mercury being thus relieved from the pressure of the atmosphere did not fall down to its original situation, but stood 0.32 of an inch higher than before, by which mercury was proved to be an expansible, and consequently a compressible fluid. The tube was now emptied, and water which had been long boiled to clear it from any air it might contain, was substituted in the place of the mercury and treated in the same manner, when the water was found to stand 0.43 of an inch higher when relieved from atmospheric pressure, than it did before, from which Mr. Canton concluded that water is slightly compressible, though to so small a degree as to be of no consequence in any practical application of it. This experiment was however on a very small scale, and nothing farther has been done towards ascertaining the quantity of condensation that water would admit of until the present period when Mr. Perkins, who lately arrived in this country from the United States of America, has tried some very ingenious and decisive experiments upon it. He was first led to the subject by the contemplation of a simple, but hitherto unexplained fact, viz. that when a bottle completely filled with water and well corked and secured was sunk into deep sea by means of a heavy weight, it always returned again to the surface, either with the cork pushed into its inside, or protruded in a greater or less degree, but the contained water was in all cases rendered salt by the admixture of salt-water. It occurred to him that these effects could not take place unless water was a compressible fluid, while if it were so they were easily explained. He therefore tried the experiment, having well secured his corks with strong canvass and cement, and after being well assured of the effect as generally stated taking place, and that no security of the cork would fix it, if the depth of sea was sufficiently great, he constructed a brass apparatus similar to Fig. 68, Plate VII. in which *p p* is a strong hollow cylinder of brass, about 3 inches in diameter and 2 feet long, made perfectly air and water-tight in every part; *q q* is a piston or turned rod of about half an inch diameter, moving into the cylinder through an air and water-tight stuffing-box *r*, and *s* is a spring ring, moving upon the rod *q q*, with a sufficient degree of friction to enable it to remain stationary in any part of it; when in use, a stout brass-case with some small holes in it to admit water screws over the rod *q q* to prevent its being touched or deranged. This instrument is therefore evidently similar to a corked bottle, for the cylinder *p p* may be said to be the bottle, and the piston *q q* its cork. In using this instrument, the cylinder *p p* is entirely filled with water that has been boiled to disengage any air with which it may have been combined (page 95) the rod *q q* is then introduced into its place, and the ring *s* being pressed close down to the stuffing-box *r*, the protecting-cap is screwed over *q q* and *s*. In this state it was lowered by Mr. Perkins to a depth of 500 fathoms in the Atlantic ocean, and on raising it again, every thing was precisely as before, except that the register, or ring *s* stood 8 inches above the stuffing-box *r*, thus indicating that the rod *q q* had been forced thus much into the cylinder, owing to the compression of the water within it. In order to make this experiment more certain the same apparatus was afterwards introduced into a strong iron gun, the bore of which was afterwards filled up by water, and the touch-hole being plugged up, and the muzzle closed by a strong plate, water was forced into it by a very small forcing-pump, until a loaded safety valve guage indicated the same pressure as above, viz. 500 fathoms of water, and upon opening the apparatus, the ring *s* was again found elevated to 8 inches. This experiment is very recent, and has not yet been published, but Mr. Perkins has most obligingly communicated the result to the author, and further, and more accurate experiments on this subject are about to be tried, because before pronouncing water to be an elastic fluid, it is necessary to be certain that it is deprived of the whole of its contained air, and it must be examined under different temperatures, particularly at 40 degrees of Fahrenheit, which seems to be the closest aggregation water admits of, since it expands in dimensions both with heat and cold above this temperature.

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* Sealed or closed by fusing the end of the glass by a blow pipe, and thus permanently and effectually stopping any orifice.

Fluids have weight, and gravitate towards the earth, according to their density in the same way that solids do, but from their want of cohesion among their particles they are incapable of assuming and retaining any particular form or figure without support and assistance, and consequently they always take the form of the vessel which contains them; and they also exert a certain force against the sides of that vessel from their tendency to fall, which constitutes their lateral pressure; for fluids not only press downwards with their whole weight in obedience to gravitation, but they press sideways or laterally in all directions at the same time and from the same cause, and consequently no fluid can remain in a state of quiet equilibrium unless every part of its surface is equidistant from the center of the earth, or in what is generally called a level plane, though that apparent plane is, in fact, not a plane, but partakes of the convexity of the earth, (page 18.) And it is for the purpose of establishing such an equilibrium that fluids always run from an higher to a lower situation.

For the purpose of explaining the manner in which the surfaces of fluids become level, it may be very fairly supposed that the particles of which they are composed are placed one upon another so as to form what may be termed pillars or columns of particles as represented in Fig. 69, and supposing all the particles to be of the same size and weight, then the six which are on one side will be an exact balance to the six which are on the other (both columns being supported by the bottom of the vessel which contains them,) and their two tops will be level: but if the two upper particles *t* and *v* are supposed to be taken away, a balance can no longer exist, for now there will be 6 particles in one column, while there are but 4 in the opposite one to press against and resist them, the consequence of which will be that the tallest column will descend, and the particle *u* will fall into the situation of *w*, while that marked *x* will, with its column, ascend into the situation *v*, and thus *x* and *w* will come to the same level, and a balance or equilibrium will be again restored. Every vessel is supposed to be filled by an infinite number of such columns although two only are represented in the figure to prevent confusion. The cause of bodies floating upon fluids, or sinking in them, may be explained by the same reasoning, for whenever a solid is immersed in a fluid, it displaces a quantity of water, and consequently renders the columns of particles underneath it, shorter and therefore lighter than those which surround it. It will only then be to conceive that the two particles *t* and *v* in the last figure represent a body which is partly immersed in the water and is floating near its surface; the columns under that body will be shorter than those which surround it, but the weight of the body becomes a counterpoise to the greater length of the surrounding columns, and must in every case be precisely equal to the quantity of water which it displaces, otherwise it cannot float, for all bodies which are incapable of so becoming this counterpoise, or in other words, are so heavy that their small bulk will not permit them to displace as much water as is equal to their own weight, must inevitably sink, consequently all things which are lighter than their bulks of water will swim, and all that are heavier must sink, unless when they are placed in a boat or hollow vessel, which by its bulk enables them to displace more water than is equal their weight, and then they will float. A ship therefore of 500 tons burthen must displace 500 tons of water from the bed or hollow which it makes itself up to its water line, and in this way the tonnage of vessels is estimated.

The truth of this position is very satisfactorily proved by putting the model of a ship or any other body capable of floating into a scale, and exactly balancing it with water in the other scale. The floating body is then to be removed and placed in a small cistern previously filled quite full of water, when a quantity of it will flow over, and on again removing the floating body a vacuity of water will be found, which will be exactly reinstated by the quantity in the scale, being the *weight* of the floating body.

The balance which has been stated to take place among the columns of water may be pleasingly illustrated by the simple expedient of tying a bladder in a flaccid way over the end of a large patent lamp glass, or other cylinder which is open at both ends, when upon filling the same to a little above the bladder, it will be borne down by the weight of the water, and will continue in the same situation even when the apparatus is immersed in water, until such immersion causes the water, both within and without the glass, to stand at the same level, and whenever this is the case, a balance occurs between the pressures of the internal and external water, and the bladder will become quite flaccid, thus indicating that it is under no pressure either from above or below; on pressing the glass a little deeper into the water, the external columns will become the longest, and consequently the most powerful, and the bladder will therefore in this case be as forcibly protruded upwards into the glass as it was at first pressed downwards.

The experiment may be varied by making use of a similar glass cylinder, and different plates of metal applied to its lower end, as in Fig. 70, but then the bottom of the cylinder *y* must be ground so as to make a water-tight joint between it and the plate of metal *z*. This plate must be held up against the bottom of the cylinder in the first instance by the string *a*, which must be kept strained until the plate is introduced in the water, as many times its own thickness as the metal of which the plate is composed is heavier than water. Thus brass is about 8 times, and lead about 11½ times, the weight of its own bulk of water, therefore if the plate *z* is of brass and is half an inch thick, it will be just balanced when immersed 4 inches deep in water, or 8 times its thickness, and upon pressing the cylinder a little further downwards the string may be released without any danger of the plate falling off. The lead plate will for the same reason require to be immersed to more than 11½ times its own thickness before it will be sustained. In this experiment it is presumed there is no water in the cylinder *y*, but if any should enter, its weight must be allowed for; the pressure is therefore all external, there being nothing to act upon the upper part of the plate but the air contained in the glass, and the plates are sustained by the action of the upward pressing columns alone. If these columns are removed, then there will be no force, even to sustain a light body, and consequently substances much lighter than water may be made to remain under its surface. Thus if a plate of lead, and another of cork, or light wood, have their surfaces made so true that no water can enter between them, and the two bodies are placed in the bottom of a glass jar, the light body being uppermost, the jar may be filled with water, and still this body will not rise and float. To perform this experiment it is necessary to hold the light body down with a stick, so as to keep it in perfect contact with the heavier one, while the water is introduced, for if the least water gets between one and the other, ascending columns will be formed, and the floating body will be buoyed up.

Notwithstanding the above experiments seem to prove that the pressures of fluids are in consequence of a mechanical equilibrium, dependant upon the gravitation of equal quantities of matter acting against each other, yet on more mature examination it is found that such pressures are regulated by perpendicular height, and the area of the surface acted upon without any regard to quantity or absolute gravity, for although a pound of water can in itself produce no greater effect than is due to a pound, yet, from the properties of fluids it may be so disposed as to produce the effect of many hundred pounds. This is very justly called the *Hydrostatic Paradox*, and it may be very well shewn by the following simple apparatus, *b c*, Fig. 71, is a small vessel for containing water formed by tying a strong bladder round two circular pieces of wood, each 3 inches diameter, the upper one is fixed to the stand or board *d d*. Immediately over *c b* a glass tube *e f* of near an inch diameter and about a foot high is screwed, having an open communication into *c b*, and a wire is fixed to the bottom piece *b*, and proceeds up the tube until it is attached to the end of the scale-beam or lever *g h*, *h* is a weight acting upon *b* so as to draw it up, or bring it into close contact with *c*, and must be so adjusted that when the tube and vessel are filled with water to the height *f*, *b* will just descend and raise the weight. If the weight *h* be now examined it will not be the actual weight of the water employed, but will be found equal to that of a column of water 3 inches in diameter, and of the height *b f*. After trying this experiment unscrew the tube *e f*, and substitute in its place the large glass vase marked in dotted lines at *i i i i*, when notwithstanding its superior dimensions, and its holding a much greater quantity of water, it will be seen that it produces no greater effect upon *b* than the tube did, for when the water arrives at the same height *f* it will just raise the weight *h*, but with no greater power or force than was done by the tube, for while the height and surface acted upon (viz. the area of *b*) remain the same, no difference will arise from using different quantities of fluid, and if the tube *e f* were not a quarter of an inch in diameter, it would produce just as powerful an effect as the largest vase *i i* that could be used. The reason of this singular phenomenon is, that in the first case, although the column contained in the tube *e f* may be diminutive, yet by having communication with the water within *b c*, it produces returning columns which pressing upwards upon every part of *c*, these re-act and force *b* downwards with the same effect as if a column of the full area of *b* was in action, but no more effect can be produced than what is due to the area of *b*, consequently, when the large vase *i i i i* is used no greater effect can ensue, for the same returning columns are formed, but they cannot be greater in number, inasmuch as *b* was fully acted upon in the first instance, and will not admit of any greater action. On this principle if, the bottoms of two circular or other tubs *k* and *l*, Fig. 72, have the same diameter and area, while the tubs are of equal height their bottoms will be pressed downwards with the same force, notwithstanding their great difference in contents, for the water of *k* will in effect resolve itself into the solid cylinder shewn by the dotted lines at *m m m m*, while that of *l* will form the cylinder *n n n n*, which are equal in both cases, and all the water in *l*, which is between the solid cylinder and the sides of the vessel will press against those sides, and not against the bottom.

This principle may be further illustrated and explained by an instrument called the *Hydrostatic Bellows*, which is represented at Fig. 73, and which consists of two strong circular boards *o o*, *p p*, united together by the strong leather *q* which is sewed, and nailed round the two boards in the manner of a pair of bellows, and is water tight. A small bent tube *r*, having a funnel at its upper end, is inserted into the lower board *p p*, in such manner that any fluid poured into the funnel may run into the space *q* between the boards, and thus it may be filled with air or water. Now, presuming the tube *r* to be about 4 feet in height, and the boards *o o p p* of sufficient magnitude, which need not exceed 18 inches in diameter, if the tube *r* is half an inch bore, a man may stand upon the board *o o*, and by blowing into the upper end of the tube *r*, (his lips being closely applied to it, so as to prevent the escape of the air) he may raise the whole weight of his body without feeling any particular strain upon his cheeks; or if water be poured into the funnel, the same effect will be produced, notwithstanding the tube shall not be capable of containing more than half a pound of water, and his weight may exceed 150lbs. Such an effect may appear paradoxical, but is nevertheless dependent on the principles which have been already explained; for since all homogeneous fluids will rise to the same level, unless restrained from doing so, it is evident that upon screwing a tube of any magnitude into any part of the top board *o o* as dotted in at *s* in the figure; the water will rise in this second tube to the same height as that at which it stands in the tube *r*, and thus the two columns in *r* and *s* will balance each other. But before the tube *s* was applied, there must have been a force operating to raise the upper board, which would be equal to the weight of water in the tube *r*, and since the water would rise equally in any number of tubes which might be applied at the same time in any parts of *o o*, a similar number of forces must be in action at the same time on all parts of the upper board. According to the dimensions of the instrument above stated, upwards of 500 tubes like *s*, each being ½ an inch in diameter, or equal to *r*, might be placed upon the upper board *o o*, and since the tube *r* has been presumed to contain half a pound of water, each of the 500 tubes will contain an equal quantity, or a total of 250lbs., all of which will be maintained at the same level by the water in *r*. Of course, therefore, as these imaginary tubes do not exist, the board *o o* will be forced upwards with a force equal to the weight of water such tubes would contain, and thus half a pound of water in the tube *r* will be capable of raising 250lbs. placed upon the board *o o*. The power of this machine is ascertained by seeking how many times the area of the supplying tube *r* is contained in the area of the moveable board *o o*, and multiplying this last quantity by the weight of the water in *r*; and since fluids press according to their perpendicular height, without regard to quantity, a power almost approaching to infinity may be procured, by diminishing the bore of *r* and extending its height, and the area of the moveable board *o o*.

It is astonishing that so extensive a power, and one which is so easily obtained, should not have been applied to many useful purposes ages ago. Such an application was indeed hinted at by Pascal in the middle of the 17th century, but from the inconvenience of managing a very high column of water in pipes, or some other cause, it was never carried into effect, until the principle was revived by the late ingenious Mr. Joseph Bramah, who availed himself of it in the construction of his most admirable and well known *Hydraulic Press*, which is now used in almost every case where great pressure is required. In lieu of the bellows part of the apparatus, the leather of which would be incapable of resisting any very considerable pressure, he used a very strong metal cylinder, in which a piston moved in a perfectly air and water tight manner by passing through leather collars, and as a substitute for the high column of water, he adopts a very small forcing pump to which any power can be applied, and thus the pressing column becomes indefinitely long, although the whole apparatus is very compact and takes but little room. Fig. 74 is a section of one of these presses in which *t* is the piston of the large cylinder, formed of a solid piece of metal turned truly cylindrical, and carrying the lower board *v* of the press upon it: *u* is the piston of the small forcing pump, being also a cylinder of solid metal moved up and down by the handle or lever *w*; the whole lower part of the press is sometimes made to stand in a case *x x*, containing more than sufficient water as at *y* to fill both the cylinders, and the suction pipe of the forcing pump *u* dipping into this water will be constantly supplied. Whenever therefore the handle *w* is moved upwards, the water will rise through the conical metal value *z*, opening upwards into the bottom of the pump *u*, and when the handle is depressed that water will be forced through another similar valve *a*, opening in an opposite direction in the pipe of communication between the pump and the great cylinder *b*, which will now receive the water by which the piston rod *t* will be elevated at each stroke of the pump *u*. Another small conical valve *c* is applied by means of a screw to an orifice in the lower part of the large cylinder, the use of which is to release the pressure whenever it may be necessary, for on opening this valve any water which was previously contained in the large cylinder *b*, will run off into the reservoir *y* by the passage *d*, and the piston *t* will descend, so that the same water may be used over and over again. The power of such a machine is enormously great, for supposing the hand to be applied at the end of the handle *w* with a force of only 10 pounds, and that this handle or lever be so constructed as to multiply that force but 5 times (by the means stated at p. 55,) then the force with which the piston *u* descends will be equal to 50lbs.: let us next suppose that the magnitude of the piston *t* is such, that the area of its horizontal section shall contain a similar area of the smaller piston *u* 50 times, then 50 multiplied by 50 gives 2500lbs. for the force with which the piston *t* and the presser *v* will rise. A man can however exert ten times this force for a short time, and could therefore raise 25,000lbs., and would do more if a greater disproportion existed between the two pistons *t* and *u*, and the lever *w* were made more favourable to the exertion of his strength.

This machine not only acts as a press, but is capable of many other useful applications, such as a Jack for raising heavy loads, or even buildings;—to the purpose of drawing up trees by their roots, or the piles used in bridge building; and until the experiments of Mr. Perkins mentioned at p. 137, this machine was thought to offer the clearest demonstration of the utter incompressibility of water. It does not however appear, that any correct experiments have ever been made to ascertain whether the rise of the large piston *t* was in exact proportion to the quantity of water thrown in by the pump. It is probable this is not the case, and that the water does suffer a slight compression, although its elasticity is so small as to have hitherto escaped notice, as producing no practical or even visible inconvenience.

From the nature of Fluidity it follows, that the pressure of fluids must be very different from that of solids, for the latter can only press downwards in proportion to their quantity of matter, while the former will not only be subject to the power of gravitation, but from their want of cohesion will press laterally at the same time that they press downwards. Thus a cubic foot of water will by its gravitation, press against the bottom of the vessel that contains it with a force of 1000 ounces, but at the same time that it is exerting this force, it will also press against the four sides of the vessel, with a force equal to twice that which is exerted against the bottom, or 2000 ounces; so that its entire force to burst the vessel will amount to 3000 ounces.

The hydrostatic bellows already described (p. 145) offers a demonstration, that in estimating the pressure of a fluid, the quantity employed must not be regarded so much as its perpendicular height, and the area upon which it is acting; for, from that want of cohesion among the particles which constitutes fluidity, they may be considered, though stationary, as so many particles in motion, or beginning to move, and consequently the perpendicular pressure of fluids is subject to the same laws as relate to solid bodies in falling (p. 21) *i. e.* it will increase as the square root of the height of the column. This may be made evident in two distinct ways; first, by examining the pressure that is exerted by a column at different heights; and secondly, by collecting and measuring the quantity of water which issues through apertures of exactly the same size, but situated in different parts of a perpendicular column.

The machine shewn at Fig. 75, consists of two parallel plates of glass *e* supported in a frame *ff*, near the bottom of one side of which is a hole *g* closed by a valve *h*, opening outwards on the hinge *i*; this valve is drawn close to the hole by a string *k* passing over a pulley *l*, and ending in a scale pan *m* for holding weights. Now if any given weight is placed in the scale, two ounces for example, a certain quantity of water may be poured between the glass planes before the valve will open, but as soon as the water is sufficiently high to overcome the weight, it will be raised, and a portion of it will be discharged. By observation or calculation, the height at which the water overcomes the weight may be ascertained, and let this point be marked upon the frame as at 1. Then upon measuring this distance from the bottom with a pair of compasses, and setting it off upwards upon the frame as at 2 3 and 4, other points will be obtained equidistant from each other; and if when the water is filled up to 1 it raises any given weight, it will when it is at 2, or twice its former height, raise 4 times that weight, when at 3 or thrice its first height, it will lift 9 times the weight, when at 4, sixteen times the weight, and so on, thus showing how necessary it is to give greater strength to the lower parts of cisterns or large vessels for containing fluids, in order to enable them to withstand this lateral pressure, which increases not with the quantity of the fluid, but as the square of its perpendicular height.

The running or spouting of fluids from the sides of vessels arises likewise from lateral pressure, and is consequently influenced by the height of column, without regard to the quantity it contains; consequently, if any given quantity of water issues in a certain time from a hole in a cask or reservoir, double that quantity will issue from another hole of precisely the same dimensions, if it is situated four times as deep as the first below the surface of the fluid, and a similar hole nine times as deep, will deliver three times as much fluid in the same time as may be readily ascertained, by catching water from orifices so situated in vessels, and measuring the respective quantities delivered in equal times. The discharge is therefore as the square root of the depth beneath the surface, which law is of great importance in the practical construction and arrangement of water works, for supplying houses or towns with water for domestic or other purposes, and if not attended to, may occasion great waste of power; for these works consist entirely of pumps or other machines, by which the water is raised from wells or natural streams in low situations into reservoirs elevated above the situation to be supplied, or containing condensed air, which acts by its elasticity when they are called air vessels. (See Air Vessel, as described with the Forcing Pump, in the next section). From these the water is conducted down again through pipes laid underground in the streets, and from thence again by smaller pipes into the houses. The essential difference in the construction of water works consists however in the use of an open elevated pond or reservoir, or that of an air vessel. By the first no supply of water can be effected which is at a greater elevation than that of the reservoir, because the operation of works of this construction depends entirely on the circumstance of homogeneous fluids finding their own level (as explained page 140) but when an air vessel is used, water may be elevated to any required height within the power and strength of the machine, since air appears to be elastic and condensable in an unlimited degree, (p. 115.) The air vessel likewise possesses this important advantage, (particularly when the power of steam is resorted to for raising the water,) that by its means the power may always be regulated to the perpendicular height to be supplied, or in other words, the quantity of operative power may always be diminished as the height of the column diminishes; while an open reservoir must be placed above the greatest height to be supplied, and all the water, even for the lowest supplies, must be forced into it to descend again at a very great expence and loss of power.

The ancient method of supplying towns with water, was by means of aquaducts, or bridges built over the vallies, and supporting either pipes or an open conduit or channel. These stupendous and costly erections, the remains of which still adorn the ruins of some ancient cities, and which exist in a more perfect state in the neighbourhoods of Paris and Lisbon, could not have been constructed for want of a knowledge of fluids rising to their common level, but probably from the practical difficulty of uniting a long range of pipes, in such a manner as to remain perfectly water tight against the pressure of a heavy column of water, a circumstance which is by no means easy, even in our present state of improvement, and with all the advantage of cast iron and the most durable materials, instead of stone or earthen ware, which appears to have been chiefly resorted to for pipes in the formation of the older water-works.

The New River water-works, which are of such vast importance to the comfort and health of the great metropolis of England, is in itself a species of aquaduct, and unites all the varieties in the construction of water-works. The spring that supplies it arises at Ware, in Hertfordshire, and its waters are conducted in an artificial channel or cut, formed for their conveyance alone, which sometimes is raised by arches and embankments very considerably above the natural surface of the ground, and at others sinks deeply into it, for upwards of 38 miles. At length it ends in the open basin or reservoir, called the New River Head, at Islington, which is sufficiently high to supply the lower parts of the town by its natural descent into the pipes. To accomplish the rest, a powerful steam engine is placed near this reservoir, for the purpose of working pumps which force a part of the water into still more elevated reservoirs on Pentonville Hill, and in the Hampstead Road, and what these cannot command, is effected by an air vessel attached to the pumps of the steam engine, so that the greater part of London is supplied without the expence of any other power than the water's natural gravitation, and the remainder by the well appropriated power of a steam engine, the nature of which will be found explained at the close of the next section.

What has been said upon water-works equally applies to fountains, for a *jet d'eau* can only be produced by the effort of water to rise to its level, or by its being under the influence of condensed air or some other force. Thus, if an elevated cistern or reservoir be kept supplied with water, and a tube descend from its lower part, and finish with a small orifice pointing upwards, the water will spout from it, and form a jet nearly equal in height to that of the water from which it is supplied; but for want of that support which the fluid derives from the sides of a tube or close vessel, and from its being in constant and rapid motion through the resisting air, it will never gain the same height or level as the column of supply, particularly if conducted through a long series of conduit pipes, which, by their friction, will considerably impede the flowing of the water. (See friction of Water Pipes in Hydraulics.)

The manner in which fountains may be produced by condensed air, is entirely dependant upon modifications of the principles explained at page 115, and as will be hereafter noticed; but their construction admits of several ingenious and amusing variations, among the best of which may be included what is called Hero's Fountain, and the Fountain at Command, both of which have a paradoxical appearance, the first seeming to raise the water above its natural level, while the second appears to obey the dictates of the person using it.

Fig. 76, is a section of Hero's Fountain, which may be made either of tin, copper, or glass. It consists of two air tight boxes, *n*, *o*, united together by the open tubes, *p*, *q*. A basin *r* is formed upon the top of the upper box *n*, to receive the water thrown up from the jet *s*. The tube *p* opens into this basin at *r*, and passing through the upper box *n*, without any communication with it, proceeds to very near the bottom of the lower box *o*; while the tube *q* opens into the top of the lower box *o*, and proceeding through the bottom of the upper box *n*, terminates very near to the under side of the basin. The jet pipe passes through the bottom of the basin, and terminates very near to the bottom of the upper box *n*, which must be filled with water by unscrewing the top of the jet pipe when the instrument is to be used. If now the basin *r* be suddenly filled with water, a jet will immediately spout from *s*, and will rise to an elevation very nearly equal to the length of the tube *p*, whatever it may be, and having the appearance of the water in the basin being raised above its level. This instrument is, however, nothing more than a condensed air fountain, in a different form to that which has already been described, (p. 115.) For the water poured into the basin runs down the tube *p* into the lower box *o*, which, being previously full of air, that air becomes condensed by the pressure of the column of water in *p*, and, having an uninterrupted communication by the tube *q* with the air above the surface of the water previously introduced into the upper box *n*, that water is forced up into the jet *s* by the action of the air so condensed above it.

This machine, though a mere toy in the form above described, is susceptible of many useful applications, and is the basis of the machine used for draining the wines at Chemnitz, in Hungary—as particularly described in Dr. Gregory's Mechanics, Vol. II. p. 221.

The Fountain at Command, shown at Fig. 77, depends on atmospheric pressure; *t* is a vessel to contain water, and which must be air tight at its upper part. It is supported by the standard *v*, which is a large open tube passing very nearly to the top of *t*. There are several small jets or spouting pipes soldered into the bottom of the vessel *t*, and the whole is supported above a basin *w* to receive the water; a hole *x* is made in the bottom of the basin, of such a size, that its area may be rather less than the sum of all the areas of the spouting jets, *u*, *u*, *u*, *u*, the consequence of which is, that they will deliver water more rapidly into the basin *w* than it can escape by the hole *x*. The basin therefore soon becomes

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Fig. 69

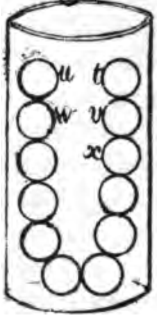
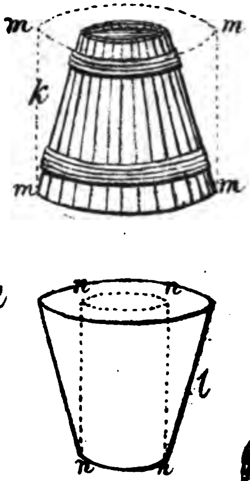


Fig. 72



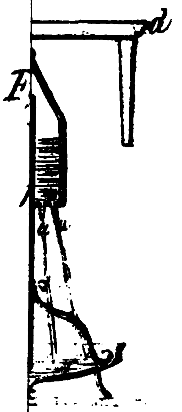
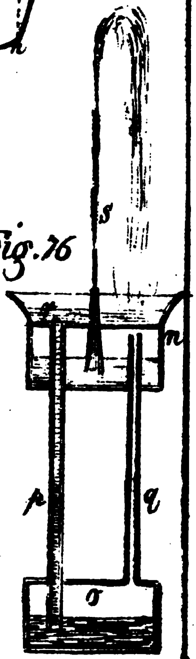


Fig. 76



:75

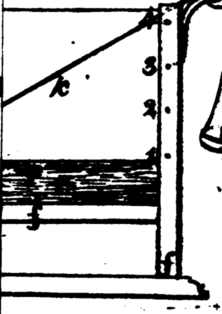
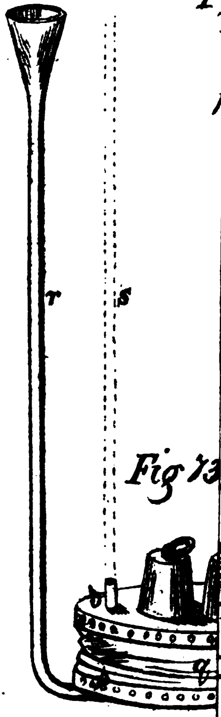


Fig 73



filled by this accumulation, and, before this takes place, the lower end of the tube *v* becomes immersed in water, by which air is prevented passing up the tube *v*, and all the jets stop or cease playing. In the mean time, the basin is emptying by the hole *x*, and the end of *v* soon becoming uncovered, a quantity of air rushes up *v*, and permits the jets to play again until their accumulation once more shuts up the passage of the air. A person watching the successive accumulations and depressions of the water in the basin, will see when the tube *v* is about to be opened or closed, and may thus appear to command the fountain to play or stop without any contact or communication with the same. To fill the vessel *t*, it must be removed and inverted, and the water is poured in by the tube *v*. The water is retained in the vessel by atmospheric pressure, when the bottom of this tube is closed.

Jets, in a variety of forms, may be screwed on to the spouting pipes of all the various fountains, and thus the water is made to issue in a single stream, or in any number of streams, in various directions, or in a fan shape, or extended sheet, at the pleasure of the operator.

It has already been shewn (page 140), that the cause of bodies floating upon the surface of fluids, depends upon a mechanical balance being produced between themselves and the fluid upon which they float; for no body can swim or float without sinking a certain distance into the fluid that sustains it; and, consequently, a certain quantity of that fluid must be removed or displaced, and that quantity will in all cases be equal in weight to the weight of the body so sustained. A boat, for example, floating on sea water, will sink to a certain depth in it; but when that boat sails up a river, and is supported upon fresh water, it will sink deeper, because sea water is more dense and heavy than river water, and, consequently, a greater quantity of the latter than of the former must be displaced to equal the weight of the boat; and, consequently, if a body is so heavy that the immersion of its entire mass cannot displace as much fluid as is equal to its weight, no balance can take place, but the body will preponderate, and must sink. Still, however, the body so sinking, although it cannot displace as much fluid as is equal to its weight, will displace as much as is equal to its bulk, and, therefore, its weight, or power of descent, will be diminished by a force equal to the weight of the actual quantity of fluid which is so displaced. This establishes a most important principle in Hydrostatics. That *every body, heavier than its own bulk of the fluid in which it is immersed, looses just so much of its weight, as is equal to the weight of that bulk of such fluid:* and, upon this principle, the method of obtaining the specific gravities of bodies in a great measure depends.

The very nature of flotation proves the truth of this proposition, but it may be experimentally illustrated in the following manner by *the Hydrostatic Balance*, which is nothing more than a good pair of small scales, having hooks under their pans for the purpose of hanging things to them, and being suspended at such a height from their stand as to admit of placing glass jars under them, to contain water for the purpose of weighing such bodies in water. Fig. 78, Plate VIII. represents a balance so arranged, the use of which will be hereafter explained.

If now a solid cylinder or cone of metal *y*, be made to fit exactly into the inside of a vessel of similar shape *z*; *z* will be a measure of the solid capacity of *y*, and if *y* be hooked upon the bottom of *z*, and *z* is hooked to the bottom of one of the scales of the balance, so that the whole may move freely in the empty glass jar *a*, weights may be placed in the opposite scale of the balance *b*, until an equilibrium is produced; but upon filling the jar *a* with water, the solid body *y* will be bouyed up and appear to loose much of its weight, notwithstanding its density, is such that it would sink in the water were it not for the counterpoise weights in *b*. The equilibrium will however be immediately restored, by filling the hollow vessel *z* with water, which proves that the loss of weight that *y* sustained by immersion, was exactly that of its own bulk of water, otherwise the filling of *z*, which is equal to its bulk, could not have restored the balance. The materials of which the solid *y* is composed cannot affect the experiment, for if it were formed of zinc, which is the lightest, or of platinum, which is the heaviest of the metals, still it could in no case displace more fluid than equalled its own bulk, and consequently every substance of the same dimensions heavy enough to sink, would suffer the same apparent diminution in weight upon submersion.

This important circumstance offers the simplest possible means of obtaining what is termed *the Specific Gravity* of heavy solids; and since the identity of substances is in many cases only to be ascertained by their specific gravities, so their ascertainment is of the highest importance, not only in scientific researches, but in a mercantile point of view.

The mere weighing of a body in a balance in the open air, as commonly practised, simply gives the weight, or gravitating power of the body weighed, without respect or reference to its density, or the mechanical arrangement of its particles; for a pound of cork will gravitate as powerfully as a pound of lead, but the bulk of the cork will be much greater than that of the lead, to produce this equal effect; and consequently, if equal bulks of cork and lead were weighed against each other, the lead would appear to have a much greater gravitating force belonging specifically to itself, than the cork has. The specific gravity therefore of a body is merely a comparison of its gravitating force against that of some other body which has been previously ascertained, and of course the material used for making this comparison, should be one as little liable to change in itself as the nature of things will admit of. Pure rain, or distilled water, is found by the experience of many ages, to be the material best suited to this purpose, as being the least liable to changes in its density at the ordinary temperatures of the atmosphere, and it is accordingly used in all experiments for this purpose, at the temperature of 60° of Fahrenheit.

Obtaining the specific gravity of a substance is, therefore, nothing more than ascertaining how much it is heavier or lighter than its own bulk of pure water, an operation which would be attended with great difficulty and nicety, were it not for the existence of the law already explained in page 156. For to obtain the comparative weight of an irregular piece of metal, and its equal bulk of water, it would be necessary to have an exact measure of its capacity to be filled a certain number of times with water, which would be difficult or even impracticable with precision and certainty; but since every substance capable of sinking in water looses as much weight by immersion, as is equal to the exact weight of its own bulk of water, it becomes easy, certain, and may be speedily ascertained, as will appear from the following account of the manner of taking the specific gravity of all such solids as are heavy enough to sink in water. Suspend the substance to be examined by means of a hair from one of the hooks of the scale pans of the Hydrostatic balance *c*, Fig. 78, in such manner that it may hang two or three inches within the empty glass jar *a* placed underneath it, without touching its sides or bottom. This done, balance it exactly by weights put into the opposite scale *b*, and note down this its ordinary weight in air; then fill the jar *a* with pure rain or distilled water, until the suspended substance is buoyed up more than its own thickness, after which the horizontal position of the balance must be restored by placing weights in the scale *c* over the suspended substance, which will, of course, depress it under the water, and these weights will indicate the weight of a bulk of water equal to that of the suspended body. The original weight in *b* must now be divided by the weight in *c*, and the quotient will be the specific gravity required; or, in other words, will shew how many times the suspended body is heavier than its own bulk of pure water. For example, suppose the suspended substance was a guinea; this weighed in air would be found equal to 129 grains; by submersion, in water the guinea would appear to loose rather more than seven grains, or so much weight must be placed in the scale *c* to restore the former balance. Then, 129 grains divided by seven grains gives a quotient of 18.00, which is the specific gravity of the guinea, and shows that the gold of which it is composed is 18 times heavier than the same bulk of water. A hair is mentioned as the most convenient mode of suspension, because it possesses the greatest strength with the least bulk to affect the accuracy of the experiment, and is not liable to absorb any sensible quantity of water. Where greater strength is required, a single or double horse hair may be used. In this and other manners to be presently spoken of, the specific gravities of almost every known substance have been carefully ascertained when they are preserved, under the title of Tables of Specific Gravities, a short example of one of which is given at the end of this section, containing the substances that were thought to be most generally useful, but which will be found much more copiously detailed in many of the larger works on Chemistry and Hydrostatics. The utility of specific gravities will now be sufficiently obvious, for by their means the purity or impurity, and identity or non-identity, of many things can alone be proved. Thus, for example, the guinea before spoken of might have been formed of an alloy of copper and tin, with its surface merely gilt over in such manner as completely to deceive the ear by its sound, and the eye by its appearance, while it might have the full weight of

129 grains, by giving it a little additional thickness to compensate for these metals being lighter than gold. Still, however, on taking the specific gravity of this base coin, the deception would become evident, for the quotient in this case would give somewhere about 8.00 for its specific gravity, thus showing, that, when compared with the standard water, it was much lighter than the metal it professed to imitate; and, in this way, the actual value or purity of the precious metals can alone be accurately ascertained. In Chemistry and Mineralogy, a knowledge of specific gravities is equally essential for proving the purity and identity of substances. Thus, in many cases, those minerals called the cubic sulphuret of iron, and crystallized bright white cobalt, are so nearly similar in appearance, that the nicest eye cannot distinguish them with certainty; but the specific gravity of the first is always between 4.6 and 4.8, and that of the latter between 6.3 and 6.5. So, again, the strength and purity of spirits, the acids, solutions, and infusions, can alone be ascertained by their specific gravities, for sulphuric acid, without any material change in its appearance, is found to vary from 1.09 to 1.81.

In the construction of tables of specific gravities, since pure water is taken as the standard of comparison, it is always represented by unity or 1, with any required number of decimal cyphers behind it, to allow of expressing the ratios of other gravities in decimal parts. Of course, those things which, bulk for bulk, approximate very closely to water in weight, or have nearly the same specific gravity, will vary very little from the expression of unity. Those, in like manner, which are heavier than water, or would sink in it, are expressed by whole numbers or integers and fractional parts; and those that are lighter than water, or would float upon it, want the integral number, and are expressed by fractions only. Thus, water being 1.000, distilled vinegar is 1.009, or very little heavier, while cast lead is 11.352, and naptha 0.708.

Pure gold is 19.258, but in this state it is too soft and ductile to be fit for general use, accordingly coinage gold is alloyed with $\frac{1}{9}$th of copper, by which it becomes harder and more capable of wearing without change of form, and in this way its specific gravity is reduced to near 18.0 as before mentioned. Jewellers gold, of which trinkets are usually made, contains a greater proportion of copper, which gives it a redder colour, and makes it still harder but much more light and brittle.

It follows from the circumstance of water being considered as unity in computing specific gravities, and from a cubic foot of water also weighing 1000 ounces avoirdupoise, that the weight of any given quantity of material of which the specific gravity is known, may be easily computed; for the same figures that denote the specific gravity, also express the number of ounces in a cube foot of the same substance; thus a cubic foot of Portland stone weighs 2,570 ounces, a cubic foot of lead 11,352 ounces, and one of naptha 708 oz.

When substances are so light as to be incapable of sinking in water, a different mode of treatment to that which has been described, must be adopted for obtaining their specific gravities, for now some force is necessary for producing their submersion, and this may be effected in several ways. Thus a small pulley moving with little friction may be attached to the bottom of the water jar, or to a weight sufficiently heavy to cause it to remain steadily there, and the hair attached to the substance, must in this case pass downwards under the pulley, and rise again so that its opposite end may fix to the hook of one of the scale pans, as at Fig. 79, in which *d* is the floating substance to be examined, *e* the jar of water, *f* the pulley at the bottom of it, and *g* the opposite end of the hair hooked on to one of the scales of the balance. The substance *d* is first to be weighed in the scale in the ordinary manner, and afterwards placed in the jar as shewn in the figure; water must then be added, until the substance by floating draws the scale beam into an horizontal position, after which weights must be placed in the opposite scale until the substance is sunk or drawn under the water. Suppose the body under examination to be a piece of cork weighing 30 grains in air, then it will be found that about 150 grains must be placed in the opposite scale to sink it, and this weight must be added to the original weight of 30 grains, making 180 grains for the weight of a bulk of water equal to that of the cork. The original weight 30 gr. must now be divided by the weight of water 180 gr. (which of course can only be done fractionally) the result of which will show that the specific gravity of cork is negative, or less than the standard by above 6 times, consequently it cannot be expressed by an integer, but will come among the fractions, being but 0.240.

Those who do not possess a sinking pulley as above described, may find the specific gravity of a floating solid by the following means; weigh the solid in air as before, and then take a weight sufficiently heavy to sink it in water, and note down the respective quantities; then attach the floating solid to the weight, so that both may be submerged while they hang to the scale of the balance, and ascertain how much the weight loses by the buoyancy of the solid, which added to its own weight in air, gives the weight of its bulk of water as before, when the operation may proceed as already described, or if preferred may be worked by the rule of three for the weight of the bulk of water displaced, is to the standard 1.000 as the weight of the solid in air is to a fourth term, which will be its specific gravity.

The above processes apply to solids only, since it would be impossible to treat fluids in the same way on account of their mixing with the water. The specific gravity of fluids may however be found in a variety of ways. Thus, the box containing every Hydrostatic balance should contain a thick glass bulb, of sufficient solidity to sink in every fluid, and likewise a weight which exactly counterpoises it, and which is to be placed in the opposite scale. The weight in air of this bulb taken in grains is always marked upon its surface, or that of its counterpoise to save loss of time in weighing it. The bulb hangs by a hair or fine platinum wire from the hook of one of the scales, over the centre of the water jar, as shewn at Fig. 80. Being balanced, the jar is to be filled with water, which will elevate the bulb, and weights must be placed in the scale over it until the balance is again restored. Such weights will of course indicate the weight of a bulk of water equal to that of the bulb. The jar is now to be removed, and another containing the fluid to be tried, is to be substituted in its place. Should this fluid be brandy, or any thing that is specifically lighter than water, the bulb will sink, and part of the weights must be taken away, but should it be sulphuric acid, or any heavy fluid, it will rise, and more weights must be added to restore the balance. The respective weights being noted down will give the following proportion, viz. The weight of the bulb in water is to its weight when immersed in any other fluid, as 1.000 the standard number of water is to the specific gravity sought. Thus, if the bulb loses 40 grains by immersion in water, and 75 grains in sulphuric acid 40 ; 75 :: 1.000 is to 1.875 the specific gravity sought.*

This experiment may however be made without the bulb, and with no other apparatus than a common phial and a pair of scales, as follows: balance an empty phial by shot or any other counterpoise in a pair of scales: then fill it with pure water and note its weight in grains, pour the water out, and having again filled it with the fluid to be examined, weigh it again, when the weight of the water will be to 1.000, as the weight of the second fluid is to its specific gravity sought.

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* The counterpoise is sometimes made to balance the Glass bulb *in distilled water*, which may not always be at hand, and thus the trouble of weighing it in water is saved.

One of the most accurate and convenient methods of obtaining the specific gravities of fluids is, by what is called a thousand grain bottle. This is sold by most of the philosophical instrument makers, together with a weight which is an exact counterpoise for the bottle when filled with distilled water; its magnitude being adjusted by grinding down the length of its neck until it holds exactly 1000 grains of water at 60° of Fahrenheit. This instrument consequently requires no computation, but is simply to be filled with fluid and placed in one scale of a balance, while its counterpoise is placed in the other. If the fluid put into it is lighter than water, it will appear deficient in weight, and as many grains must be added to the scale that contains it as will restore the balance. This at once shows that the specific gravity of the fluid under examination is negative, or less than the standard, and consequently must be a fractional number; but should the fluid be heavier than water, the bottle will preponderate, and weights must be put into the opposite scale, when their amount will be positive, and must be added to the amount of the standard. For example, if the bottle were filled with sulphuric ether, it would require 739 grains to be placed in the same scale to restore the balance, consequently its specific gravity would be thus expressed 0.739. Had it been filled with sea water, which is rather denser than that which is distilled, 26 hundredths, or rather better than ¼ of a grain must have been added in the opposite scale, and these as already explained, must be added to the standard 1.000 to express the specific gravity of such water, which would be thus written 1.026. Sulphuric acid again, being still heavier, would in like manner require 875 grains, and would accordingly be expressed 1.875.

By inspection of the Table of Specific Gravities it will be seen, that adding any matter which is heavier than water to it, either as a solution or infusion, increases its density, and consequently its specific gravity, while all wines and spirituous liquors are lighter than water, and become more light in proportion to their purity up to pure alcohol itself, which is only 0.825.

It follows, therefore, that the knowledge of specific gravities is of the greatest importance to brewers, distillers, and others, who are concerned in the fabrication of these liquors, since they offer the only correct means of estimating their strength and comparative value, and since the revenue duty upon spirits is estimated upon their strength, so of course it likewise must depend upon a similar basis. Any of the processes which have been described would answer the purpose of this investigation, were they sufficiently convenient and expeditious, but the instrument called *the Hydrometer*, from its great portability and easy use, is constantly resorted to in the operations of trade and commerce, notwithstanding its results are not so implicitly to be relied upon as those of the Hydrostatic Balance, unless used with great care.

The Hydrometer is said to have been invented by Archimedes, and consists of a metal or glass bulb, made so light as to be capable of just floating upon the surface of the fluid in which it is placed, and of supporting its graduated scale and compensation weights. Its ordinary form is shewn at Fig. 81, *h* generally being a hollow ball of copper, of the shape, and about the size of a hen's egg: *i* is a divided scale of thin brass placed upon the top of the ball, and *k* a brass weight attached by a wire to the lower side of the ball, for the purpose of keeping the instrument upright when it is floating; and so adjusted as to cause the top of the ball to stand but a very little distance above the surface of distilled water when placed in the same: *m* is a weight (of which there are several distinguished by different members) that drops on to a pin projecting above the top of the scale to complete the adjustment of the instrument. By such a weight the instrument is so much further depressed into the water, that the zero point, or bottom of the scale just coincides with its surface, and after this adjustment, if it is floated in a vessel containing spirits or any other fluid of less specific gravity, and consequently of less buoyancy than water, it will sink in it to a certain extent, and indicate the difference by the surface of the fluid intersecting a higher point upon the graduated scale. Should the instrument be placed in a fluid of greater specific gravity and buoyancy than water, so that the weight *m* will not be sufficient to depress the scale down to the surface, then that weight must be changed for one of higher power.

The difficulty and nicety in the construction and use of the Hydrometer arises, 1st from the circumstance of a greater quantity of matter being introduced into the fluid, in proportion as the instrument sinks more deeply, which can only be obviated by making the neck *i*, upon which the scale is engraved, so small and slender, that its whole bulk, if immersed, shall bear no sensible proportion to the bulk of the entire instrument; and 2ndly, in the susceptibility of spirits, for which the Hydrometer is chiefly used, to expand and contract with change of temperature, by which its density is subject to constant variation. The second inconvenience can only be removed by the constant use of the thermometer with the instrument, and as the divisions are made to correspond with the density of fluids at a temperature of 60° of Fahrenheit, so at this point the result as indicated by the instrument will not require correction. But since this instrument is to be used in all seasons, and it would be impossible in the extensive concerns of commerce, to vary the temperature of the fluid under examination to one common standard, so corrections must be made either by tables, calculations, or change of weights, to suit the particular exigency of the case, and several modifications of the instrument have been contrived to facilitate the process. Clark's Hydrometer, which varied very little from the one described, except that the shifting weights were very numerous, and were applied at the situation *k* within the fluid, instead of being put upon the top of the scale as at *m*, was adopted and used during a long period in the Customs, under the directions of an act of the legislature, but being found intricate and troublesome, it was superceded in 1816, by Sikes's Hydrometer, which is now generally used in England, as ordered by an Act of Parliament (56th Geo. III. cap. 140.) This instrument has but nine shifting weights, applicable upon the upper part of the stem, as in the figure, and is used with a set of tables, or a sliding rule sold with it, for computing compensation for different temperatures. The scale is divided into 10 principal divisions, each of which are subdivided into 5 parts, and by the separate application of the weights in succession, completes the range of strengths from pure alcohol to water, each weight being equivalent to 10 principal divisions. This Hydrometer with the weight marked 60, screwed as at *k* on to the lower stem, is so adjusted as to sink to the line mark P on the scale of the instrument when placed in proof spirit, of the temperature of 51° Fahrenheit, and by the addition of the square weight on the top of the stem, it sinks to the same point in distilled water of the same temperature. This weight being just one-twelfth part of the entire weight of the whole Hydrometer, together with its bottom weight No. 60, causes the scale to show the difference between water and proof spirit, which the act above referred to states, shall weigh exactly twelve thirteenth parts of an equal bulk of distilled water. No spirit is allowed to be sold for the purpose of drinking which is above proof; and proof spirit consists of half water and half pure spirit, that is, such as when poured on gunpowder in a spoon and set on fire, will burn all away, and permit the powder to take fire and flash as in open air. But if the spirit be not so highly rectified, sufficient water will remain to make the powder wet and incapable of exploding. In the ordinary use of the hydrometer, although the specific gravity is actually sought, yet it is not given in the terms adopted by science for the same purpose, but refers rather to its selling strength, or per centage above or below proof, and the divisions of the scale are arranged accordingly; thus, if the instrument sinks so as to indicate 20 above proof, it means that the spirit tried contains 20 gallons more spirit in the 100 gallons than is necessary to constitute proof spirit, or that it is 20 per cent. more valuable than proof spirit, and must be lowered by 1-5th of its own quantity of water before it is fit for sale. The other constructions of Hydrometer that are most esteemed are those of Dicas, Quin, and Jones, the latter being very simple, having but three shifting weights, and the Thermometer being attached to the instrument with such a scale that the compensation for temperature, and allowance for the mutual penetration of the fluids, is given at sight without any tables or requisite calculation.

The mutual penetration of fluids into each other affords another instance in addition to those cited at page 13, of a change of density or bulk, without change of weight, for two equal quantities of water and strong spirit when mixed will not produce double the first quantity, though their joint or separate weights are undisturbed. This, of course, presents another practical difficulty to the correct results of the Hydrometer; for if to 100 gallons of spirits of wine, found by its means to be 66 gallons in the 100 above proof, you add 66 gallons of water to reduce it to the proof state, the mixture, instead of producing 166 gallons, will produce only 162 gallons of proof spirit, 4 gallons being lost in the total quantity by the mutual incorporation or penetration of these fluids into each other, so that the specific gravity of mixtures is in very few cases the mean of their separate specific gravities.

When the instrument is used for obtaining the specific gravity of infusions or extracts, such as the strength of worts in brewing, it is called a Saccharometer when it requires a different scale, but is not otherwise very dissimilar in construction: with certain modifications and additions, as invented by Mr. Taylor, it becomes an Acetometer for determining the strength of vinegar and weak acids; and although the Hydrometer has been described as made of metal, yet it is not unfrequently formed of glass, which answers very well, but these instruments are sometimes very improperly made of ivory, which, from its power of absorption, can hardly be expected to give two results alike.

The Thermometer makers of London prepare small glass bubbles, like beads, but hermetically sealed and formed of different weights, so that while some will float upon the ordinary brandy of commerce, others will sink in it, and the specific gravity of these bubbles being ascertained by trial, is marked with a diamond upon them, and they become very useful instruments for trying the comparative goodness of spirits; for if a bubble be found which just sinks beneath the surface of good brandy, it will sink to the bottom in that which is still stronger, and float above the surface of that which is not so strong. The figures 5, 10, 15, &c. marked upon these bubbles, indicate per centage strengths as in the Hydrometer, but are not so much to be depended upon unless used with a Thermometer at the temperature at which they were originally formed. They answer, however, very well for the cursory examination of spirits above hinted at.

The obtain the specific gravity of Gasses requires a process rather different from any yet described, and the best which has yet been devised is that described in the first volume of Dr. Henry's excellent Elements of Chemistry, p. 126, which is briefly as follows. The gasses to be examined should be received over mercury in a receiver with a stop-cock, as shewn at *n*, Fig. 82—the contents of such receiver, in cubic inches, having been previously ascertained and marked on a scale upon its side. The gass must be quite pure and well dried by exposure to proper substances to absorb its moisture in the usual way. A glass mattrass or flask must likewise have a cap and stop-cock fitted to it as at *o*, by which it is to be screwed to a good air pump and exhausted as perfectly as possible, in which state it must be very accurately weighed, and then screwed on to the cap of the receiver *n*, when by opening the cocks very gently any required number of cubic inches of the gass, as estimated by the scale upon *n*, may be admitted into the flask *o*, when, upon shutting its cock, it may be unscrewed and weighed again. In this manner 100 cubical inches of atmospheric air will be found to weigh about 30.5 grains, the same quantity of oxygen gass will weigh about 34 grains, and of carbonic acid gass upwards of 47 grains. In comparing the weights of different gasses the height of the Barometer and Thermometer must be observed, and 30 inches for the former, and 60° for the latter, is taken as the standard. Should this pressure or temperature vary, the volume of gass must be reduced to it, by rules which are too long to be admitted in this work, but which will be found fully detailed under the title of Weight of Gasses in Professor Brande's Manual of Chemistry, page 117 (first edition). Knowing the weight of atmospheric air, the specific gravity of any gass, as compared with it, will be readily ascertained; for if 100 cubic inches of common air weigh 30.5 grains, and the same quantity of oxygen gass weighs 34 grains, then 30.5 : 34 : : 1.000 : 1.1147 the specific gravity required. Or, it may be determined likewise more simply, by weighing the flask; first, when full of common air, and again when exhausted; and, afterwards, by admitting into it as much of the gass under examination as it will receive, and weighing it a third time. Then the loss of weight, between the first and second weighing, is to the gain of weight on admitting the gass, as 1,000, or the assumed weight of common air, is to the specific gravity sought.

The subjoined Table contains the specific gravities of some of the Gasses, Precious Stones, Metals, and such other materials as were thought most useful. Those who have occasion for more extended tables may consult Dr. Young's Natural Philosophy, Vol. II. p. 503, or Professor Brande's Manual of Chemistry, from which authentic sources this Table has been compiled.

TABLE
OF
SPECIFIC GRAVITIES.

REFERRED TO AT PAGE 159.

	To Air.	To Water.
Hydrogen Gass	0.084	0.000096
Nitrogen Gass	0.985	0.00120
Atmospheric Air	1.000	0.00128
Oxygen Gass	1.103	0.00137
Carbonic Acid Gass	1.500	0.00176
Cork		0.240
Naptha (the lightest fluid)		0.708
Muriatic Ether		0.729
Sulphuric Ether		0.739
Pure Alcohol		0.825
Nitric Ether		0.908
Olive Oil		0.915
Bees Wax		0.964
WATER. The Standard		1.000
Wort for Table Beer		1.025
Cows Milk		1.032
Wort for Ale		1.095
Isinglass		1.111
Plumbago or Black Lead		1.860
Ivory		1.917
Sulphur		1.990
Brick		2.000
Nitre		2.000
Common Salt		2.130
Porcelain		2.384
Black Flint		2.581
Rock Crystal		2.653
Slate		2.671
Emerald		2.775
White Glass		2.892
Flint Glass		3.329
Diamond		3.521
Beryl		3.548
Fluor Spar		3.175
Hyacinth		3.687
Spinette Ruby		3.760
Oriental Topaz		4.010
Crude Antimony		4.064
Sapphire		4.076
Bohemian Garnet		4.188
Oriental Ruby		4.283
Molybdena		4.738
Arsenic		5.763
Cast Antimony		6.702
Cast Zinc		7.190
Cast Iron		7.207
Cast Tin		7.291
Bar Iron		7.788
Cast Nickel		7.807
Cast Cobalt		7.811
Hard Steel		7.816
Soft Steel		7.833
Cast Brass		8.395
Cast Copper		8.788
Cast Bismuth		9.822
Pure Cast Silver		10.474
The same hammered		10.510
Cast Lead		11.352
Mercury		13.568
Trinket Gold		15.709
Gold Coin		17.647
Pure Cast Gold		19.258
The same hammered		19.361
Pure Platinum		19.500
The same hammered		20.336
Platinum Wire		21.041
Platinum laminated		22.069

SECTION VIII.

HYDRAULICS.

AS that branch of science called Hydrostatics contemplates the weight and pressure of fluids, and their action upon bodies placed in them, so HYDRAULICS is more particularly confined to the motion of fluids and the construction of those instruments or machines by which such motion is produced and regulated.

The motions of Fluids are produced by their own natural gravity; by contact with other bodies already in motion; or by artificial force or pressure, as in the various pumps or machines for raising water. It is the first of these causes which induces water to run from a higher into a lower situation whenever it has an opportunity of doing so, which will account for the currents of all rivers running from their springs or sources into the sea, where the water spreads or equalizes itself over the aqueous part of the globe, so as to be equidistant from the centre of the earth. unless when it is disturbed by tides, winds, or other local causes.

A question naturally arises upon the perpetually descending currents of rivers, that since they are ever flowing downwards without any reciprocation, whence is the perpetually elevated source derived, and how happens it that it never becomes exhausted? Rain, and those natural springs of water which flow from the bowels of the earth, naturally present themselves as affording the necessary supply. Rain, which has been before spoken of, and explained (p. 112.), no doubt performs a very active part in producing these effects, but still the quantity of rain which falls in any particular district will, when measured, be found in almost all cases quite inadequate to the supply of those springs which are constantly and regularly flowing; for the general effect of rain is to swell our rivers suddenly, and produce floods and inundations, which are very different from the constant and regular supply of springs. Whenever rain falls upon the ground, or snow begins to melt, a great quantity of the water will be absorbed into the ground, and will go in aid of the formation of springs, and upon this cause; there is no doubt but that they depend in a great measure, but, at the same time, the slow and almost insensible evaporation and condensation which is constantly going on in the atmosphere, is much more likely to afford the constant supply of water which they require, than casual and occasional showers of rain or snow.

Dr. Halley, when residing in the island of St. Helena, for the purpose of forming his catalogue of the stars in the southern hemisphere, had his attention drawn to the subject of spontaneous evaporation, by finding the glasses of his telescopes continually covered by aqueous vapours, even when the atmosphere appeared clear, notwithstanding he was placed near 800 yards above the level of the sea; and the researches he made on this subject proved that the quantity of water taken up by the air, was much greater than had been before expected. He calculated, that at the general temperature of St. Helena, 10 square inches of the surface of the sea yielded 1 cubic inch, or $253\frac{1}{3}$ grains Troy of water to evaporation in every day of 12 hours, and consequently that a square mile of the ocean would yield 6914 tons of water in the same time; a quantity amply sufficient to account for the production of all springs upon the land, as well as to show how the Mediterranean sea might be constantly receiving a fresh influx of water without overflowing. As the dry and heated air of the equatorial regions is capable of taking up a much greater quantity of water in vapour, than the colder air of other climates, it must not be supposed that an equal evaporation takes place in every part of the globe, and indeed it has since been found that the quantity estimated by Dr. Halley is much too great. It has however been pretty clearly ascertained that nearly 1-third more water rises in evaporation than is returned to the earth again, as rain, snow, or hail, and consequently it may be presumed, that this additional quantity is quietly and imperceptibly deposited upon the earth as dew or mist; and since this deposition is constantly produced by cold, and the upper regions of the atmosphere are much colder than those below, so the principal quantity of recondensed water will be furnished to the tops of hills and high eminences which likewise attract the clouds towards them, and thus may the existence of springs of water in very elevated situations be accounted for, since it is by the process of evaporation alone, that water could be naturally conveyed into such exalted positions.

The generality of springs therefore depend upon a supply of water thus furnished, and augmented by occasional showers. The water so supplied sinks into, or percolates through the ground, until it meets with a stratum of soil, such as clay, stone, or the like, that is impervious to its further passage downwards, and which of course obliges it to accumulate, until by its effort to descend to a lower situation, it breaks through the soil, and shows itself as a spring on the surface;

or should it have no such opportunity of escaping, it remains latent until opened by the sinking or digging of a well down to the depth at which it may chance to settle. Springs cannot therefore be considered as veins of water running through the earth in particular directions, as they have formerly been supposed to do, which is sufficiently proved by the circumstance, that pumping one deep well so as to drain it for a few weeks will effectually dry all the other wells for a great distance around it, which could not take place were the springs disconnected, instead of being dependant upon the stratification of the country in which they occur; and thus it will be seen that geological knowledge is of the greatest importance in searching for water, for when the nature and order of the strata of a district are known it becomes an easy and almost certain problem to say, whether water will be found or not in it; and in many cases the depth that must be opened to find it may be defined with considerable accuracy.

In order to ascertain the quantity of water that falls upon the earth as rain, an instrument, called a *Rain Guage*, is used. This usually consists of a large tin or copper funnel, such as is used for filling bottles, but so constructed that its open top shall expose some given superficial measure such as a square foot or a square yard. This funnel is fixed upon the top of a building of sufficient height to prevent its being influenced by eddies or artificial currents of air, and its top is completely open to the atmosphere to receive any rain that may fall, while the tube proceeding from its bottom passes downwards into a chamber immediately beneath, and terminates in a close bottomed glass tube or phial which is graduated into cubic inches of capacity. This tube, which should not be of large diameter, in order to prevent evaporation, receives the rain that falls into the funnel, and gives its comparative measure by inspection; for in an instrument of this kind, it is not necessary to measure the actual quantity of rain that falls at a given place in a given time, but merely to compare the quantity of one particular time or season with that of any other time, either under similar or dissimilar circumstances. Accordingly in some Meteorological Journals, it will be found recorded that in a certain month, May for example, the quantity of rain that fell at a certain place was equal to 1.75 of an inch. In the month of August the rain was 7 inches at the same place, &c. all which merely indicates that the sum of all the showers of rain that happened during the month of May, produced a deposit of water in the tube equal to 1 cubic inch and ¾, while the rain that fell in the whole month of August produced 7 cubic inches, or was 4 times as great; and in the same way the quantity falling in any one year may be compared with that of any other, and with the state of the barometer, clouds, winds, and other atmospheric phenomena. This comparative quantity of rain is all that is necessary for meteorological purposes, but by knowing the area of the funnel, and comparing it with any larger space, the quantity of rain that falls upon a town or large district may be obtained, since by knowing the quantity that falls upon a square foot, it is a matter of great ease to calculate the quantity that would fall upon a square acre, or even a square mile; but the computation must not be carried to too great an extent, because it frequently rains in one place while it is fair in another, and therefore to determine the quantity of rain that falls upon a large district of country, an average must be taken of the results of a number of rain guages set up in different situations upon it.

Water is actuated by the same power of gravitation that affects solid bodies, and consequently if it falls perpendicularly its motion will be accelerated in the manner already explained (p. 21.) When it flows in a current or stream, as in rivers or channels, it does so in consequence of the end of the channel towards which it is flowing being lower than that from which it proceeds, in which case its motion is referable to that of solids descending inclined planes; but from the want of cohesion among the particles of fluids, their motions are much more irregular than those of solids, and they involve a number of intricacies of very difficult solution, and which are rendered still more uncertain in their investigation, by the few experiments that have been accurately tried on a large scale to furnish data for calculation. A solid, when moving, is from its very nature constrained to move altogether, and the friction, that occurs between it, and the surface upon which it moves can be very accurately ascertained, but not so with a fluid, for while one part of this may be moving rapidly, another may be quite stationary, moving slowly, or even moving in a contrary direction. This is particularly observable in rivers where the central part or main current will always be found flowing with much greater rapidity than either side, and experiment proves that the same effect occurs when water flows through pipes, for that water which is in contact with the side of the pipe moves with much more resistance than that at the center, whereby the supposed or calculated discharge of any given pipe of considerable length becomes much less than is due to its magnitude. The term Friction, is applied to this obstruction to the passage of fluids, in the same manner as it is to solids, and it exists to such an extent as to become an object of considerable inconvenience in practice. It can only be obviated by making the conveying pipe of much larger dimensions than would otherwise be necessary, so as to allow the free passage of a sufficient quantity of fluid through the center of the pipe, while a ring or hollow cylinder of water is considered to be at rest all around it. Other circumstances besides friction likewise tend to diminish the quantity of fluid which would otherwise pass through pipes, such as the existence of sharp or right angled turns in them, and permitting eddies or currents to be formed, or not providing for the eddies or currents that form naturally by suiting the shape of the pipe to them. It follows therefore that whenever a bend or turn is necessary in a water-pipe, it should be made in as gradual a curve or sweep as possible, instead of the form of an acute or even right angle; that the pipe should not only be sufficiently capacious to afford the necessary supply, but should be of one equal bore throughout, and free from all projections or irregularities, against which the water can strike and form eddies or reverberations, since these will impede the progress of the fluid as effectually as the most solid obstacles. These subjects have been particularly investigated and examined by Newton, Bernoulli d'Alembart, De Buat, Robison, Venturi, Dr. Young, and many others, and the following important practical results obtained from their labours are highly worthy of attention,—1st. The friction of water in rivers or channels increases as the square of the velocity.—2d. Although the sides of a pipe must in every case produce a certain degree of friction, yet that defect is frequently overbalanced by a duly proportioned size of pipe properly fixed, giving a moving direction to the fluid which it would not otherwise obtain, and by which a greater quantity of discharge is produced than could otherwise take place. Thus, for example, a vessel or reservoir having a thin bottom of tin, with a smooth circular hole formed in its bottom, might be supposed most capable of parting rapidly with its water, because the fluid in running out has no continued length of substance to rub against, and consequently very little friction could be generated, but M. Venturi found by his experiments,* that such a vessel did not discharge its water so rapidly as another containing the same height of water and area of hole to which a short pipe of the same diameter as the hole was applied underneath it, and by varying the length of pipe he ascertained, that when its length was equal to twice its diameter it produced the most rapid discharge, for being so circumstanced it discharged 82 quarts of water in 100 seconds, while the simple hole without the pipe, discharged but 62 quarts in the same time. Pursuing the same experiments he found that if the pipe instead of being applied to the bottom of the reservoir, so as to be flat and even with it, was made to project some distance into it as at *p*, in Fig. 83, it had the effect of diminishing the flow of water even to less than issued through the simple hole without any pipe. This phenomenon of a pipe and hole of similar area discharging various quantities of water under different circumstances, while the head or pressure remain the same is sufficiently accounted for by the cross or opposing currents in which all fluids move, when the conducting pipes or vessels are formed so as to oppose or divert the assisting currents that would otherwise form, and they may be examined pretty accurately by mixing Bran, powdered Amber, or other materials which will float throughout the whole quantity of water, when it will be seen that currents will form, from the top and sides of the containing vessels towards the orifice of discharge as indicated by the small arrows drawn within the vessel shewn in section at Fig. 84. These arrows do not however stop at the discharging orifice, but from the inertia of water, are constrained to cross each other and pass beyond it, hence to a certain extent they tend to stop or shut up the orifice against the passage of that water that is descending more perpendicularly, and by their contending influence cause the water that issues to run in a screw-like form. This effect is in a great measure counteracted and destroyed by the application of a short tube below the hole, but if that tube projects into the vessel as at Fig. 83, the arrows assume a new form, and those columns which descend from near the outsides of the vessel by turning up again to reach the discharging orifice, are thrown into a more direct opposition to the motion of the central descending columns, at the same time that they are themselves constrained to turn suddenly in opposition to their inertia before they can enter the pipe, and thus the discharge is more effectually impeded than if it were proceeding from a mere hole through a thin bottom.

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* Experimental Enquiries concerning the motion of Fluids by J. B. Venturi, translated by William Nicholson, 1 vol, 8vo. London, 1799.—See also a Paper by Dr. Young, on the motion of Fluids, applied to the circulation of the Blood.—Phil. Trans. 1808.

Sir Isaac Newton investigated the curves in which a fluid will proceed from the interior of a reservoir to a discharging orifice in its bottom, and found that the solid figure produced by the streams flowing from all parts to one common center, viz. the orifice of discharge as indicated by the arrows in Fig. 84, was an Hyperboloid of the fourth order, and Venturi from finding the great difference of discharge through the same area of opening as before stated, determined on applying a discharging pipe of this, the natural form of flowing water, to the bottom of a reservoir as shewn at Fig. 85, when he found that although the bottom orifice *q* was the same as before, the quantity discharged was increased to 98 quarts in the same period of time; and conceiving that the curve which water naturally assumes in running, was continued beyond the point of discharge, he likewise enlarged the lower or discharging end of the delivering pipe by making it bell or trumpet mouthed in the same curve, as at Fig. 86, and from this form he obtained the maximum quantity of water that could be delivered through a given orifice.

It will be evident that these examples do not refer to extended lengths of pipe, but merely to the rapid discharge of water from reservoirs, and they are merely given here to show by what simple means the flow of water may be impeded or increased in practice. The motion of Fluids, and the friction and other causes by which it is impeded forms one of the most elaborate and abstruse branches of Mathematical Philosophy, but is of too abstract a nature to be admitted in the present work. It may be practically assumed that water may flow through straight pipes of from 2 to 7 inches diameter, when lying horizontally, at the rate of 3 feet in a second, without much loss of power from friction, unless the length of pipe is very considerable, and consequently to calculate the quantity of water that a pipe will deliver in a given time it is only necessary to calculate the solid contents of a yard of any pipe in cubic inches or any other measure of capacity, and to multiply this by the number of seconds contained in the given time, in order to obtain the delivery. By a curious coincidence in numbers it happens, that if the diameter in inches of any pipe be squared, and the right hand figure of its square number be cut off by a decimal point, such square number will be the contents of a yard of such pipe in ale gallons and tenths with sufficient accuracy for any practical purpose. Thus if the pipe is 6 inches diameter its square will be 36, which being divided by a point as aforesaid makes 3.6 and shows that one yard of such pipe contains 3 gallons and 6-tenths. In a 10 inch pipe, the square is 10.0 consequently 3 feet of such pipe contains 10 gallons without a fraction. If the pipe were but 2 inches diameter its square 4 consists but of one figure: in this case that single figure must be considered as the right hand figure to be cut off, and the place of the left hand figure must be supplied by a cypher; thus the contents of a yard of 2 inch pipe will be 0.4 gallons or 4-tenths of 1 gallon.

The nature of the motion 'lateral pressure, gravity, and momentum of fluids being investigated by the theoretical and mathematical principles of Hydrostatics and Hydraulics,' the construction of mechanical engines for raising or moving water, and for procuring disposable power from its agency, follow as natural consequences. In the formation of these it must be kept in mind, that water has a constant tendency to descend, which affords the principal resistance to be overcome in the one case, and the source of power in the other, and as water can never rise above its ordinary level, except by some extraneous force, so likewise in descending it can never produce a power equal to the elevation of more than its own quantity to a height equal to that from whence it flowed, since this would be contrary to the laws of Hydrostatic equilibrium.

That well known implement, *The Crane*, or *Syphon*, may at first sight appear to be an exception to this rule, for it consists of nothing more than a bent tube like *r s t* Fig. 87, one end or leg of which *r* is inserted into the fluid in a vessel or reservoir to be emptied, when upon applying the mouth, or an exhausting syringe to the outer end *t* until the contained air is extracted and a part of the fluid comes over, it will be found to afford a constant and regular stream until the whole of the water is drawn off, unless previously stopped by the cock near *t*; and whenever this cock is opened, the flow of water will be resumed, even though the bend or turn *s* of the pipe be upwards of twenty feet above the surface of the water *r*. Upon a closer examination of this instrument it will be found to depend upon Hydrostatic equilibrium, for unless the leg or distance from *s* to *t* be greater than from *s* to the surface of the water at *r* the instrument will not act, as the experiment of reversing the legs, or putting the end *t* into the water will instantly show, provided the water in the vessel is at such a height as to be below the end of the exterior leg; for the operation of the syphon does not depend upon the actual length of its legs being uneven, but upon the virtual or effective legs being so, and the effective legs are from the surface of the fluid to the bend or point *s*, and from thence to the extreme point of discharge at *t*; consequently, if the leg *s r* were to be made indefinitely longer than *s t* the syphon would still run, provided the fluid at *r* was higher than the end *t*, but it would only continue to run until the surface of that fluid should be depressed down to the level of the point *t* when it would stop. The action of the syphon is simply as follows; drawing the air out of the end *t* produces a vacuum in the tube; the pressure of the atmosphere on the surface of the water *r* therefore causes it to rise and fill the tube as far as *s*, and after gaining that summit, the water continues to flow over it down to *t*; the syphon being thus entirely filled with water resolves itself into two opposing or counteracting columns which occupy the two legs of the instrument, and as fluids press according to their perpendicular height without regard to the magnitude of their column (p. 143), so it is not material that the two legs of the syphon should be of equal diameter, for if the leg *r s* is indefinitely larger than the leg *s t*, and consequently contains much more water, still if *s t* is the longest, its column will preponderate and overcome that in *r s*, and by running out at *t* will tend to reproduce or maintain a vacuum of air in the upper bend *s*, which is constantly prevented by a new supply of water being forced up *r* by atmospheric pressure (p. 100), consequently the flow will be constant so long as there is water at the end *r* above the level of the discharging point *t*, but so soon as that water becomes depressed to the level of that point which it may be supposed is raised to the dotted line *v*, then *r s* and *s v*, being equal in length, will balance each other, and no water can flow. It will appear likewise that the syphon, so far from discharging water above its level, is incapable of doing so, and that its delivery will in every case be nearly the same as would take place through a hole of equal capacity bored in the side of the vessel at the depth of the discharging point *t*, for whatever may be the length of the leg or pipe *s v t*, the descending column of water from *s* to *v* will be exactly balanced by the ascending column from *r* to *s*, consequently the entire length of the operative or preponderating column will be from *v* to *t*, therefore the lower *t* is below *v*, and the more rapidly the water will flow, while if the discharging point be raised to near *v*, the preponderating column will diminish in force, and the flow will be much more languid. As the syphon is dependent on the pressure of the atmosphere for its action, the bend *s* at its top must in no case exceed 33 feet from the surface of the water to be raised, or it will be incapable of acting. It has already been shewn when treating of the barometer (p. 102), that a column of mercury 31 inches high is a balance for, or is the greatest height of that metal which the pressure of the atmosphere can sustain when at its greatest natural density, and that as this density diminishes it can sometimes support no more than 28 inches of mercury in the barometer tube. Now as the specific gravity of mercury is 13.56, or rather more than 13 times and a half as heavy as water, it follows that if the pressure of the atmosphere can support 31 inches of mercury, it will also support above 13½ times as high a column of water, or one of about 420 inches, or 35 feet in perpendicular height, and as each rise or fall of one inch in the barometer is for the same reason equivalent to above 13½ inches of variation in the water column, so when the mercury falls to 28 inches the water column would sink to about 32 feet 6 inches. The barometer is however seldom so low as 28 or so high as 31 inches, consequently 33 feet is generally assumed as the extreme average height to which a column of water can be raised by atmospheric pressure. This is however carrying the calculation to too great a nicety for practical purposes of which I have seen many instances. When the barometer is low, it requires a perfection of vacuum bordering on the Torricillean to maintain a column of water at this height by atmospheric pressure; and I strongly recommend in the construction of all pumps and Hydraulic engines, where this agent is to be employed, that no greater perpendicular height of water column than from 28 to 30 feet be attempted. The force of these observations will be more apparent hereafter when describing the various pumps for raising water, for the portion of syphon pipe from *r* to *s* may be compared to the suction or feeding pipe of a pump, and if the perpendicular height from *r* to *s* exceeds 35 feet, the water cannot under any circumstances of atmospheric pressure rise up to *s*, but the upper part of the pipe will remain quite empty, like the space at the upper end of the tube of the barometer while the water will remain suspended at some distance below *s*, and will rise and fall with variations of the air as the quicksilver does, thus constituting a water barometer, with this difference only from the mercurial one, that while the motion of the latter is confined to the small space of 3 inches, the water of the former, from its lesser weight, will vibrate through a space of near 3 feet and a half. It is likewise necessary in using the syphon, to make the discharging point *t* sufficiently low to induce such a current of water as may prevent air rising up the discharging leg, which it will do if the tube is very large and the current languid. This may be prevented by turning up one or both ends of the syphon into the form shewn at Fig. 88, in which latter case the instrument is called a *Wirtemburg Syphon*, from the place where this form was invented. This syphon, when once filled, is constantly ready for use without any previous exhaustion, at least so long as it is kept in an erect position, for from the shape of its ends a small quantity of fluid will be retained in the bends below the dotted line *u w*, which will prevent the escape of the fluid from the upper part *x* by preventing the admission of air into the tube, and consequently whenever either end is dipped into a fluid so as to be deeper than *u*, *w*, the opposite end will begin to run.

The principal use of the syphon is to decant or draw fluids from the upper parts of vessels containing them, without tapping or making an orifice below; and it is likewise highly useful in many chemical processes for drawing off liquor without disturbing a sediment that may be at the bottom of it. It has also been very ingeniously applied by Mr. Busby to a canal lock for saving water, for which he obtained a patent a few years ago. The syphon is also occasionally disguised to form a philosophical toy, called *Tautalus's Cup*, from the well known fable. This cup has a hollow stem, as at *y* Fig. 89, into which a small glass syphon *z* is cemented in such manner that the upper bend of the syphon may be a little below the top of the cup, and the shortest leg *a* may very nearly touch it. On pouring water into the cup it will rise to its proper level in the tube *a*, but still the cup will hold water, but on attempting to fill it, the water will still rise up the tube *a* until it reaches the bend, which it will flow over and thus fill the whole of the longer leg *z b*, and the instant this is effected the water will flow continuously from *b* until the cup is quite emptied. The upper part of the syphon *z a* may be hidden, by placing a hollow image of a man over it with the chin on a level with the bend of the syphon, when the cup will hold water until filled to the chin of the figure, but the water will begin to flow away as soon as it reaches that point. The syphon may even be formed by the hollow figure without a bent pipe, for if *c*, Fig. 90, be a straight pipe fixed through a hole in the bottom of a vessel, and a small receiver or tube *d* closed at the top, be inverted over it, this will immediately form a syphon, and as soon as the water rises to *e* on a level with the top of the pipe *c* it will begin to flow.

A very beautiful *jet d'eau* may be formed on a small scale on the principle of the syphon, as follows: *f* is a tall glass receiver with a close top, and *g* a brass cap cemented in an air-tight manner over its lower end. This cap is pierced with two holes *h* and *i*, into the first of which *h*, a small adjutage or spouting pipe is fixed with its small end upwards, while the lower end projects a few inches below the cap. To the hole *i* a pipe *i k* of about a quarter of an inch in diameter is adapted, and equal in length to the height of the receiver *f*; this last pipe does not stand above the bottom of the cap but is level with it. When so prepared, if the instrument be inverted or held with the receiver *f* downwards until a sufficient quantity of water is poured in at *k* to rather more than fill the tube *i k*, and it is then turned back into its upright position, as shewn in the figure, the water so introduced will flow back again down *i k*, and will thereby cause a rarefaction of air in the receiver *f*, and consequently if the lower end of the jet pipe *h* be now immersed in a vessel of water *l*, that water will rise through the jet to near the top of the receiver, and as the water so supplied continues to run down the tube *i k*, the jet of water will of course continue so long as the pipe *h* is supplied with water. The bottom of the pipe *i k* should either be turned up, or stand in a cup of water to prevent air rising into *f* particularly if the jet pipe *h* is very small.

From the above description it will appear that although the syphon does raise water above its level, yet it can only do so for the purpose of afterwards discharging it at a lower point, and consequently this instrument cannot be admitted among the number of those which are for the express purpose of raising water above that height to which it would not flow, but for the exertion of some extraneous force. Engines of this kind may be divided into two classes, viz. those of the simplest and most ancient construction in which the water is lifted or conducted by the mere exertion of force, and those of a later and more refined description in which the pressure, or elasticity of the atmosphere, momentum or moving force, alteration of temperature and other philosophical principles are brought into play.

The most simple and obvious means of raising water from a lower to a higher situation is unquestionably by the use of a bucket and rope or chain winding round a windlass, as in the common draw-well, but whenever the depth is great this becomes a tedious and expensive operation. Such a mode of working would however soon lead to the improvement, of using a succession of buckets instead of a single one, and this is the foundation of two of the most ancient Hydraulic machines, known by the names of the Persian Wheel and the Screw of Archimedes, as well as those more recent contrivances the Bucket Engine and the Chain Pump.

The Persian Wheel, shewn at Fig. 92, must be rather more in diameter, than the height to which it may be necessary to raise the water, and must stand in the stream or reservoir from which the water is to be taken; it consists merely of a rim or circle of wood supported by arms or spokes from the central axis or gudgeon *m*, upon which the wheel revolves in a vertical direction. Upon its circumference a number of buckets or boxes, as *n*, *o*, *p*, and *q*, are hung by iron loops or eye bolts upon round iron bolts in such manner that these boxes may constantly hang upright as the wheel revolves, and since the lower boxes *n n n* are constrained by the motion of the wheel to dip into the water *r r*, they will become filled, and will carry up their charge of water as at *o o o*, until at length arriving at the highest point *p*, they all in succession come into contact with the cistern *s*, by which they are tilted up, and discharge their contents into it, and having passed over it they descend on the opposite side *q q* in an empty state, and are ready to be filled again by dipping into the water. Motion may be given to this wheel, either by the power of animals, or if *r r* is a running stream with sufficient water to spare, by equipping the circumference of the wheel itself with vanes or float boards similar to those of the wheel of any water mill, in which case it will raise up a portion of that water by which it is itself driven round. Small springs *t t* are fixed to each of the buckets at that part which comes into contact with the side of the cistern *s* for the double purpose of breaking the violence of the blows which the buckets would otherwise give to the cistern, and likewise for more effectually tilling the buckets to enable them the more completely to discharge their contents. Simple as this machine may appear to be, yet it is one of the most cheap and effectual that can be put up for irrigating land for farming or gardening purposes, where it may be necessary to raise a part of the water of a running stream into a higher situation. It requires no care or attendance while working, and as it moves incessantly while the stream runs, it will carry up a very considerable quantity of water even if its buckets are made but small, and the smaller they are, and the less power will be required to give motion to the wheel. It likewise requires none of that nicety in its construction which is usually necessary in millwork, but will act if made in the roughest manner. It may likewise be applied in many cases with advantage to the tail stream of a water-mill when water is scarce, so as to work by the water after it has passed the mill-wheel in order to raise and return a portion of it, instead of letting it all run to waste.

Nearly allied to the Persian Wheel, but much more elegant and elaborate in its contrivance is *The Cochlion*, or *Screw of Archimedes*, a machine invented and used by this philosopher, for raising water and draining land in Egypt about 200 years before the christian æra. The Cochlion consists of a succession of buckets or recesses to be filled with the water to be raised, but instead of their being separate and detached as in the last described machine they are formed by the lower parts of the hollow thread of a screw, and their motion and succession are brought about by turning that screw. This will be better understood by referring to Fig. 93, which is a representation of this machine, and in which *v u w x* shows a flexible tube or pipe wound in a screw-like form round a solid cylinder *y y*, the two extreme ends of which are equipped with pivots, so that the cylinder with its encircling screw-formed tube may be made to revolve on its axis by the force of running water, or any other power applied to its upper or lower end. Lastly, this machine must be supported by its two pivots, so as to make an angle with the horizon as shewn in the figure. If now the lower end *v* of the tube be supposed to be covered with water, that water will flow to its own level within the tube, and will occupy the lowest bend *v*, and if now the cylinder *y y* be turned round by its handle *z*, in the direction of the arrow near *v*, the lower end of the spiral tube will become elevated above the surface of the water in the reservoir, and that water which had entered into the tube will have no opportunity of escaping, but by the motion of the screw tube will flow within it until at the end of the first revolution it will be found in the second lower bend *u*. In the mean time the lowest extreme end of the tube will have made a second dip into the water of the reservoir, and will receive a second charge, which in like manner will be transferred to *u* at the next revolution, while the water lately at *u* will be elevated to *w*, until at length when the cylinder has made as many revolutions as there are turns of the tube round it, each lower bend will become filled with water, whatever may be the length of the cylinder *y y*, and as the extreme upper end *a* of the tube becomes depressed in each revolution into the situation of a lower bend, it will there discharge its water into an elevated cistern *b* placed to receive it. The quantity of water raised by this machine will depend upon the capacity of the screw pipe, and the angle above the horizon at which it is placed to work; but it will be seen by the figure that there is room to dispose several pipes parallel to each other round the same cylinder, when they will all work simultaneously, or the whole cylinder itself may be made into a hollow screw by merely placing a thin screw-formed diaphragm or partition round its central axis, which is the most usual form of the machine in practice. On a small scale, it may be constructed by wrapping one or more flexible lead pipes round a solid cylinder of wood, which forms a useful machine for raising water to small heights. It was formerly much used, but owing to its liability to become choaked by mud, weeds, and other impediments, and the great difficulty of cleaning it out, it is seldom met with. It has from its specious appearance of seeming to throw the entire weight of water, that it is raising upon its axles, and the little friction with which these may be made to move by friction rollers, had astonishing powers ascribed to it, and has formed the foundation of many a perpetual motion scheme; but if investigated it will be found that the water is merely made to flow up an inclined plane; and whether water, or any other weight be drawn up a fixed inclined plane, or it be stationary until moved by an inclined plane being forced under it, as is the case with the quantities of water contained in the several bends *v u w x*, &c. the mechanical effort will be the same, consequently this machine possesses no other mechanical advantage over other constructions except that its motions are attended by less friction than belongs to most of them.

The principle of the Archimedian Screw is occasionally adopted in the wheel-form by making the spokes or radii hollow and curved, as shewn at *c c c* Fig. 92, but in this way the water cannot be raised higher than the center or axis of the wheel, for the hollow spokes being open at the circumference of the wheel, dip into the water and receive their supply, which from the wheel's motion, and their peculiar form is carried to the axis, which may either be hollow to receive and carry away the water, or a cistern may be placed under it to receive the water from the arms.

The *Bucket Engine* and *Chain Pump* are but modifications of the above described machines, and are very useful in particular situations. The chain pump is shewn at Fig. 94, and consists of a number of flat plates or discs of wood or metal *d d d* which are usually square, and are connected together through their centers by an iron rod, with joints between each board, so as to permit them to turn with nearly the same freedom as if they were connected by a chain. The chain of plates so formed is supported and kept in its place by two wheels *e* and *f*, each being furnished with double projecting arms to lay hold of and support the plates in succession, and in such manner that if the upper wheel *e* is turned by a winch, it will cause the whole chain to move, one side of it passing upwards while the other descends continually in the same direction. The ascending side of the chain is made to pass through a considerable length of square box or trunk *g g*, which by fitting pretty closely to the plates forms the pump. The lower wheel *f*, as well as the lower end of the trunk must be under water, and the chain of plates passing upwards through the trunk produces a succession of chambers or cavities, that become filled with water which is eventually discharged from the top. From the formation of this pump it requires to work in deep water, and consequently cannot drain a reservoir to the bottom, but it has the advantage of not being liable to choak, and will even bring up mud, stones, and such weeds and chips as would entirely destroy the operation of a more perfect machine, and notwithstanding it may be supposed to loose much of its power, owing to the plates not fitting very accurately into the trunk, yet as an upper chamber can only leak into one that is below, and the motion of the plates is very rapid, it will when properly constructed bring up a very considerable quantity of water. If the top and bottom wheels *e* and *f* are supposed to be retained while the trunk *g g* is taken away, and a number of buckets similar to those upon the wheel Fig. 92, are attached to the chain, instead of the square plates *d d d* then the machine becomes a bucket engine, which is but another form of the Persian wheel already described. There are many more machines of this class for raising water, but the examples already given embrace the principles of most of them, and it would be quite beyond the limits of this work to attempt to describe the whole of them.

The *Rope Pump* of Vera, described in most books on Hydraulics, consists likewise of an upper and lower pulley, formed in the ordinary manner, but with several grooves in each, in which endless ropes of very loosely spun horsehair or wool are made to move with great rapidity by a multiplying wheel connected with the upper pulley. The lower pulley, together with a great part of the rope, moves in the water which is merely brought up by adhereing to the ropes and the rapidity of their motion. This therefore is but a very imperfect and rude kind of bucket pump, and is by no means deserving the place it has so long held in the catalogue of Hydraulic machines.

The second class of contrivances for raising water, or that in which they act upon certain philosophical principles, comprises all those machines to which the name of *Pump* is more particularly applied. Of pumps there are several varieties, but the simplest and most common is *the ordinary lift* or *Household Pump*, which depends chiefly on the pressure of the atmosphere for its action. This useful machine is one of great antiquity, its invention being ascribed by Vitruvius to Ctesebes of Alexandria about 120 years before Christ; but the principles upon which it acts were not understood until long afterwards, as appears by the very lame explanation of them that is attempted by Galileo towards the beginning of the 17th century. The nature of atmospheric pressure was not however at this time at all understood, and it is a curious fact that the experiments made upon this now common machine should have led to the invention of the barometer by which the variations of the atmosphere have since been so accurately investigated.

The form and construction of the common lift pump has already been so fully described under the head Pneumatics, (see page 99, and Fig. 58, Plate VI.) that it will be needless to enlarge upon it in this place further than to observe, that all that has been said of the action of the syphon at page 185, equally applies to the pump, for if the piston, at its greatest elevation, should at any time exceed the distance of 33 feet from the surface of the water in the well, there is a chance that the working of the pump may not produce a sufficiently perfect vacuum to raise the water. It may not be amiss likewise to notice another frequent error in the construction of pumps which is very detrimental to their action, namely, making the feeding pipe, or that pipe which proceeds from the water to be raised to the bottom of the working barrel, (or from *q* to *s* in Fig. 58) of too small a capacity, under a notion, that if this pipe is large, the piston in ascending will have to raise and draw after it a much thicker column of water, and consequently a much greater load than is necessary. The fallacy of this supposition has been already shewn by the experiments upon the Hydrostatic paradox, page 143, for whether a column of water be pressing downwards upon a piston as there described, or that column of water be underneath an ascending piston and is drawn upwards by it, as is the case in a pump, the circumstances of pressure will always remain the same, and will be regulated only by the perpendicular height and horizontal sectional area of the column. The working barrel of the pump or the piston that works in it will therefore always determine the area of the column, and whether the pipe that carries the water up into it, or upwards from it, be greater or less, the effective force to work the pump will be the same, friction only excepted. If therefore the working barrel *m m* Fig. 58, is supposed to be 3 inches diameter, and the suction or feeding pipe *s q* to be but one inch, still the small quantity of water contained in this pipe will exert the same effective force to draw the piston *t n* downwards, as if it were of the same diameter as the working barrel. It would do the same thing if it were but of the tenth part of the capacity just mentioned, and it could do no more if it were ten times, or any indefinite number of times larger than the working barrel. It will therefore appear that no mechanical inconvenience can result from having the suction or feeding pipe of the same diameter throughout, as the working barrel itself, although a serious inconvenience must arise from having this pipe too small, for unless the water can flow up the feed pipe to fill the vacuum made under the piston as rapidly as that vacuum is formed, the piston will be prevented from rising, by the pressure of the atmosphere acting downwards upon it, and as the hand applied at the handle *p* cannot distinguish between atmospheric pressure and the resistance to the water's rising the pump will seem to require much more force to work it than is due to the column it is lifting, or than would be necessary if it were permitted to receive its full charge of water without restraint. This is however a very common practical error, and many a pump of the best workmanship and construction has obtained a bad character from having too small a suction pipe, or being placed at too great a height above the water it has to raise.

Notwithstanding the common lifting pump is incapable of raising water from more than 33 feet (or rather 30 feet, see page 185) below the place where it may be fixed; yet it may be made to deliver water at almost any required height above its piston by the application of a continued straight pipe instead of the cistern head shewn at *o v* Fig. 58. Thus if that cistern head and spout be supposed to be taken away, and 20 or 30 feet of close iron pipe to be added to the top of the working barrel *m m*, since the water once raised cannot pass downwards again through the valve *t* in the piston or bucket *t n* it must continue to rise with each stroke of the pump until at length it will flow over the top of the pipe, or through a spout inserted in any part of its side. In this case atmospheric pressure has nothing to do with the elevation above the piston, consequently it may be carried to any height that the strength of the pump will admit of, but the handle *p p* (or any other contrivance by which the pump is worked) must be fixed above the top of this pipe, and the piston rod *o* must be equal in length to the pipe in order to keep the working barrel within the limits of atmospheric pressure, which makes this arrangement of pump inapplicable to very great depths on account of the bending of the piston rod. Where cast iron pipes are used, this may be in a great measure prevented by placing small pieces with projecting arms of sufficient length to touch the inside of the pipe at each joint of the piston rod, or about 10 or 12 feet asunder, as shewn at Fig. 95; when this pump may be used for considerable depths with advantage.

When the well, or source of water is not deep, and it is required to send the water to a considerable height, the great length of piston rod just noticed may be dispensed with, by inverting the whole arrangement of this pump, that is to say, placing the piston below, and the stop valve and delivering pipe above, as shewn at Fig. 96, where *h h* shows the inverted working barrel, and *i* the inverted piston and rod with a valve opening upwards; *k* is the stop valve placed at the top, instead of the bottom of the barrel, and also opening upwards into the rising pipe *l l*, which may be continued to any height required; the lower end of the working barrel is quite open, and must stand in, and be covered with the water it has to raise, so that no suction or feed pipe is necessary to this pump, and the piston *i* may be worked by a handle and series of levers *m*, *n*, *o*, or in any other convenient manner. After the description already given of the common lift pump, it will be needless to say any thing on the action of this machine, as it is presumed the figure will render it sufficiently obvious: while the lower end of the working barrel *h h* is immersed in water, and the piston *i* moves upwards and downwards, the barrel will be filled through the piston valve at each down-stroke, and at each up-stroke its contents will be expelled through the stop-valve *k* into the ascending pipe *l l*, and whatever the diameter of this pipe may be, still its resistance will constantly be equal to the weight of a column of water of the size of the working barrel, and of a height equal to the *perpendicular* altitude of the water in the ascending pipe; for this pipe may be placed horizontally or obliquely so as materially to alter its length, but it is the perpendicular height between the surface of the water to be raised and its point of discharge, which must alone be taken into account in estimating the load upon a pump since increase of length, without height in the pipe produces no other resistance than that of friction, which is most easily overcome by increasing the capacity of the pipe.

A very simple, cheap, and efficacious pump on the lift principle may be constructed in the following manner, and will be found very useful in draining foundations or ponds: where there is sufficient room for it to work, it is shewn at Fig. 97, in its proper position for working, that is when placed at an angle of about 45 degrees with the surface of the water it has to draw, though it will work very well at a greater or less elevation. It consists of a long trunk or square box, formed by nailing four strong boards together, their insides being planed smooth, and the joints made air-tight by white lead ground in oil. A similarly formed, but smaller box of about a foot long slides into the bottom of the large trunk for the purpose of forming a seat for the lower valve, which is made of a piece of very strong leather nailed at one side only on to one of the sides of the short box, so as to form a hinge, and with the exception of this hinge the whole of the leather is covered by a square piece of plank firmly nailed to it to strengthen the valve, which must play (without contact) in the inside of the large trunk. In using the pump this hinge should be uppermost, and the valve is made on a separate short box for the facility of removing it for repairs or cleaning the pump, but when in use it must be screwed or wedged in its proper place. The piston consists of nothing more than a square cap or hollow pyramid of very strong leather firmly nailed on to the end of a pole previously fitted to it, and which is to act as the piston rod; for which purpose it has a T headed handle by which it is worked by any requisite number of men, who sit by the side of each other upon a bench to work it, their feet resting against a foot board firmly fixed to the ground. The action of working this pump is exactly similar to that of rowing a boat, for in moving forwards to depress the piston, the leather pyramid collapses and passes through the water in the trunk without resistance, and even permits stones, chips, and materials, that would choak an ordinary pump to pass it, but on drawing up the piston, the pyramid extends itself so as to come into contact with the four sides of the trunk, and brings the water and every thing before it. The water is delivered into a wooden shoot and passes off under the bench upon which the men sit to work, and in drawing up the piston their bodies are thrown back and almost straightened, while their feet press against the foot board, and thus the body is thrown into the best possible position for the exertion of its strength. From the weight of water that a trunk of this kind will contain, and the force necessary to work it, it becomes necessary to encompass it with iron screw tyes as shewn at *q q q*, otherwise the joints will open and admit air: *r* is the piston rod, *s s* the T handle, and *t* the hollow leather pyramid or piston, as it appears when withdrawn from the pump; it is formed of four isoceles triangles of very strong leather, mitred together at the sides that come in contact, and strongly sewed in a water-tight manner. In using this, as well as all other pumps, to draw muddy or sandy water it is always adviseable to set the bottom of the pump in a close wicker basket or other strainer, because sand and small stones very soon destroy the leather, and working parts of any pump, and when pumps are used for hot liquors, which is the case in many manufactories, thick hempen canvass must be substituted for leather, unless the valves and piston are made entirely of metal. It may appear that the pumps described at page 197, and shewn at Figs. 95 and 96, are applicable to every purpose and to every situation, such as raising water from mines and the deepest places, but this is not the case, owing to the almost imperceptibly small elasticity of water, and the effects of the *vis inertiæ*, which belongs to fluids in common with solid manner. In working the pump shewn at Fig. 96, if we presume the pipe *l l* to be full of water, that water has not sufficient elasticity to permit the barrel *h h* to discharge its contents through the valve *k* without putting all the water contained in *l l* into motion, while when the piston descends

page 156 to 200.

Fig. 78.

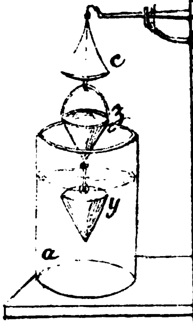


Fig. 82

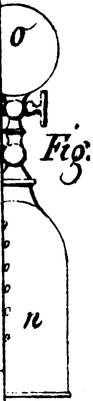


Fig. 83

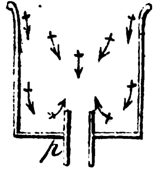


Fig. 84

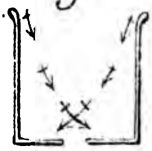


Fig. 85

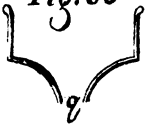


Fig. 86.

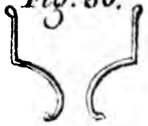


Fig. 87

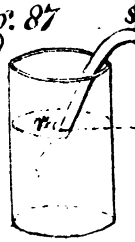


Fig. 94

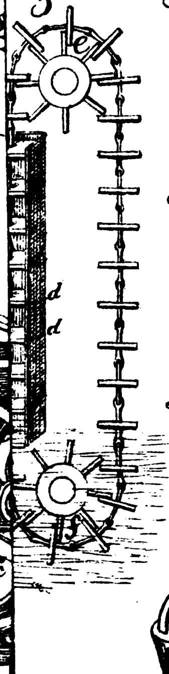


Fig. 95

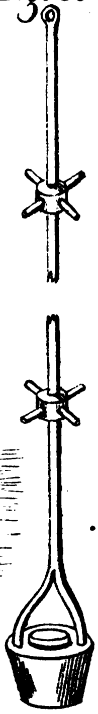


Fig. 91

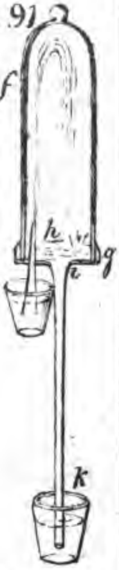


Fig. 92

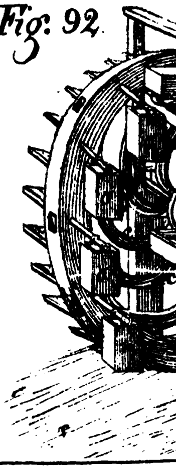
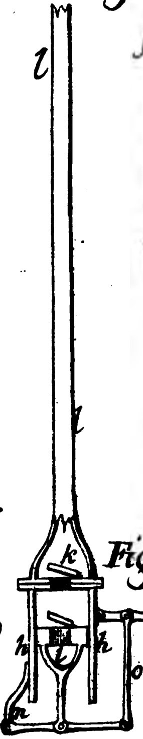


Fig. 96.



that motion will be at an end. The water in *l l* will therefore be in an alternate state of rest and motion, and if the column is long, and its quantity great, the *vis inertiæ* will be very considerable, that is to say, it will require a considerable exertion of force to get it into motion from a state of rest; and when it has once begun to move it will have no immediate tendency to return again to rest, but might be continued in its motion with less force than that which was originally employed to move it, (pages 6 and 16.) The descent of the piston however allows sufficient time for all the motion that was communicated, to be completely lost, and hence in working this pump we not only have the weight of the column to overcome, but the natural inertia to combat with at every stroke. This may in great measure be removed by keeping two, or what is still better, three pumps constantly at work by what is called a triple or three throw crank, and accordingly this expedient is generally resorted to in all small engines for throwing water to a great height, for by this means the water is never permitted to stand still in the pipes, but a constant flow or stream is maintained. The triple crank is an axle of iron, bent into the form shewn at Fig. 98, Plate IX. so as to form 3 elbows *v u w*, to each of which the piston rod of a pump is attached by a swivel joint, while the whole revolves on two end bearings or pivots *x y*. The consequence of this is, that while the piston rod *b* connected to the crank *w* is at the very lowest point or bottom of its stroke, the piston rod *a* with its crank *u* is very nearly at its greatest height, but the rod *z* and crank *v* are horizontal and in the middle of their stroke; the pump connected with *v* would therefore be the only active one in the present state of things, but if the crank is supposed to be in motion, before the rod *z* gets to the bottom, *b* will have began its ascending and *a* its descending stroke, so that by this contrivance one pump is always brought into effective action just before another ceases to act, and thus a constant stream is produced. To give the triple crank its most perfect action, the three cranks or arms should make angles of 120 degrees with each other, or when viewed from either end *x* or *y* should stand like the three radii *c d e* drawn separately near the last figure.

In most cases of raising water, that construction of pump called the *Forcing Pump* may be resorted to with advantage, particularly when the pump is of large dimensions, and the height to which the water is to be raised is great, for this might endanger the distortion or breaking of the crank. The forcing pump is likewise generally used in conjunction with an air vessel, or strong metallic box to contain condensed air, the spring or elasticity of which enables this pump to produce all the beneficial effects of a constant current with one, or at most two barrels, instead of the three that are necessary with the triple crank, and thus a considerable portion of friction is avoided.

The forcing pump is made in two forms, suited to the situation and circumstances under which it has to work. The simplest and best construction is shewn at Fig. 99. It consists of a truly bored cylindrical working barrel *f f*, the top of which is quite open to admit the solid piston *i* which works in it in a perfectly air and water tight state, by means of the lever or handle *g g*, or any other more convenient application of power; *h* is the feeding pipe, dipping into the water to be raised as in any other pump, and this pipe may of course be made of any length under 33 feet (see page 185); *k* is the stop valve, covering the top of the feed pipe, and permitting water to rise into the working barrel as the piston ascends, but not permitting it to return again; so that whenever the piston is raised by its handle *g* the barrel will be filled with water forced up the pipe *h* by atmospheric pressure, and when the piston descends again, since there is no valve in it to permit the water to pass through it, it will be forced up the lateral pipe *l* (opening into the bottom of the working barrel), and through the valve *m* which prevents its returning back again, so that it is constrained to find its way up the rising pipe *p p* fixed above the valve *m*, and this pipe may be continued to any required height, without regard to the pressure of the atmosphere, since the ascent of the water does not depend upon its action, but upon the mechanical force that is applied to the handle *g* to depress the piston. While the piston rises to fill the working barrel the valve *m* will be shut, and of course all motion of the fluid in the pipe *p p* will cease, and hence the use of the air vessel *n*, for it will be seen that the pipe *p p* is not joined on immediately above the valve *m*, but that it passes through the top of an air tight copper or other hollow vessel *n*, and proceeds nearly to the bottom of it. Air being a lighter fluid than water will of course occupy the upper part of this vessel, and as soon as the action of the pump has filled it with water up to the dotted line *o o*, or just above the lower end of the open pipe *p p*, all air that is above the water will be confined and unable to escape. If now the working of the piston be supposed to throw water more rapidly into the air vessel than it can escape by the pipe *p p*, it is evident that such confined air will be condensed into less compass than it naturally occupies in order to make room for the water; and as the elasticity of air is constant and increases in power with its degree of condensation without limitation (see page 115), so the spring of the air in the air vessel will become a counterpoise, or equivalent for any height to which the pipe *p p* may be carried, and although the water in the pump explained at page 198, Fig. 96, would not admit of eondensation, so as to permit a fresh quantity of water to enter the ascending pipe without putting all its contents into motion, yet the introduction of the air vessel obviates this difficulty, for now the new quantity of water is not delivered unto a former quantity of inelastic water, but into a vessel filled with air which readily allows a change of dimensions, and while the piston *i* Fig. 99, is rising and projecting no water, the previously condensed air in *n* has time to re-expand into its former volume by expelling an equivalent quantity of water up the pipe *p p*, and thus if the air vessel is large enough a constant and equable current may be maintained.

Fig. 100, shews the other form of the forcing pump, though this construction is generally called *The Lift and Force Pump.* Its formation is the same as the last described figure, except that the piston is not solid, but is perforated, and covered by a valve opening upwards as in the common lifting pump, the piston rod *q* likewise moves in an air-tight manner through a stuffing box or collar of leather on the top of the working barrel which in this case is closed, and the lateral delivering pipe with its air vessel proceeds from the upper, instead of the lower part of the working barrel. This pump not only has the stuffing box, but three valves, instead of two as in the last example. It is consequently rather more intricate and expensive in its construction, with no other advantage than that it is rather more cleanly in its working; for if the piston of the former pump is not quite water tight, a quantity of water may flow over the open top of its working barrel, which cannot be the case in this pump if well made. Their action is very nearly alike, for this last pump raises water through the suction pipe *h* by the elevation of the piston *i*; on depressing the piston that water passes through it by its valve, and gets above it to fill the upper part of the working barrel; on the reascent of the piston, that water being unable to escape at the top of the barrel on account of the cover and stuffing box *x* is forced up the lateral pipe *l* into the air vessel, and from thence passes away by the ascending pipe *p* as before. The first pump raises water by the down and this by the up stroke, but this is easily changed if required, by adopt-ing a lever of the first, instead of one of the second kind (page 50) as shewn in the figure.

The air vessel shewn at Fig. 99, likewise differs from that in Fig. 100, because the delivering pipe *p* of the first passes through the top, and the latter through the bottom of the air vessel, but they both proceed from near the bottom, and in either case when the water has risen to the dotted line *o o*, so as to cover the lower end of this pipe, the air will be confined and their operations must be alike. The air vessel must be suited in its capacity to the magnitude of the pump or pumps that deliver water into it, (for several pumps are frequently made to open into one common air vessel), and ought in all cases to contain at least six or eight volumes of the pump, in order that the increasing expansive force of the air may not influence the motion of the piston during a single stroke, but for this no precise rule can be given, as the relative dimensions may vary to suit the circumstances of the case. These forcing pumps with air vessels are now very generally adopted in water works for supplying cities or towns (see page 151), and the height at which the water is at any time delivering may be very nearly estimated if the air vessel is large, and the supply equable, by examining the degree of condensation of the air within it. This is very conveniently done by a guage, consisting of a glass tube with a close top, applied by a stop-cock to the lower part of the air vessel, or that which is always filled with water; thus, *r s* Fig. 99, represents such a tube, and as it has an open communication with the air vessel, when the cock is open, the air in the top of the tube will suffer the same condensation as that within the vessel. The height of the space occupied by air within the tube must be measured, and as the air at its ordinary density will balance a column of water 33 feet high (see page 185) so if confined air is loaded with the weight of such a column, it will shrink or be condensed into half its former bulk.

Whenever therefore the air contained in the tube *r* is diminished to half its original length, the condensation within the air vessel must bs equal to two atmospheres or what is the same thing the water in the pipe *p p* must stand at the elevation of 66 feet. If the water in *p p* is raised to thrice 33 feet or 99 feet, then the condensation within the air vessel must be equal to 3 atmospheres and the air within it, as well as within the tube, will be diminished to 1-third of its original bulk.—One-fourth of the bulk will indicate 4 atmospheres of condensation, and be equal to the elevation of the water column to 132 feet, and so on, more or less, as the barometer may vary.

That useful machine, *The Fire Engine*, or engine for extinguishing fires, is nothing more than two forcing pumps of the construction shewn at Fig. 99, working into one common air vessel placed between them and from which the spouting pipe for directing the water upon the fire proceeds. The handles are so disposed that while the piston of one pump is up the other is down, and they are elongated for the purpose of enabling a great number of men to work them at the same time, for the purpose of throwing a very large quantity of water which is rendered a continuous stream by the action of the air vessel. It is curious that the most ancient pump we are acquainted with, namely, that of Ctesebes, at least as it is handed down to us, very closely resembles the present fire engine, for it consists of two forcing pumps, disposed as just described, but instead of discharging their contents into an air vessel, they merely deliver them into an intermediate close cistern, from which the water ascends by a perpendicular pipe, and in which nothing is wanting but the condensation of air.* It must however be observed, that both the pumps shewn at Vig. 99 and 100, would be forcing pumps without their respective air vessels, and though they act much more equably and advantageously with them, they are sometimes constructed without these useful appendages.

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* See Ctesebes's Pump, article *Pump*, in Dr. Hutton's Mathematical Dictionary, Vol. II. p. 304.

Before dismissing the subject of pumps, one more must be described which is the invention of M. de la Hire, and which produces the effect of two pumps with the friction of one only, for it is a lift and force pump that raises an equal quantity of water by its up and down stroke. We have but few instances of its adoption, and considering its advantages, it is surprising that it is not more frequently put into practice. It is shewn in section at Fig. 101, *t t* being the working barrel, in which the solid piston *v* moves up and down, *u* is the feeding pipe, and *w* the stop valve upon it; *x* is a lateral pipe proceeding upwards from the bottom of the working barrel until it terminates in the under part of the air vessel *y*, such termination being closed by a valve opening upwards into the air vessel, from which *z* is the discharging pipe. So far this pump precisely resembles that shewn and described by Fig. 99, both in construction and action; but in the present pump, instead of the working barrel *t t* being open at its top it is closed by a cap, and the piston rod *a a* works in an air-tight manner through the stuffing box *b*, consequently when the piston is depressed to expel the water out of the lower part of the working barrel into the air vessel through the pipe *x*, a vacuum will be formed in the upper part of the working barrel, and this is supplied by water through a second feeding pipe *c* also descending into the well, and having a stop valve *d* applied to it in a chamber or cavity *e* formed for that purpose; the upper part of this second suction pipe opens into the top of the working barrel above the greatest height to which the piston can ascend, and thus by its descent is that part of the barrel which is above the piston completely filled with water, while the lower part of it is emptying; and when the piston ascends again, all the water that has been so deposited above it, is forced up the pipe *f* into the same air vessel *y*. The pipe *f* is likewise closed at its upper end by a valve opening upwards to prevent the return of the water when the piston descends, and thus by the alternate action of one piston moving in one barrel is all the beneficial effect of two pumps produced.

Since it is impossible when a pump is well made and is in good order, that its piston can move without displacing the water that is above or below it, according to the circumstances of its construction, so in all pumps that consist of cylindrical working barrels and pistons, nothing more is necessary to ascertain the quantity of water they will deliver, than to calculate the solid or cubical contents of that part of the barrel in which the vacuum is produced, and to reduce this to some standard measure, and then to multiply this by the number of strokes made in a given time; thus if a pump is 9 inches diameter, and makes an effective stroke of about 18 inches, such a cylinder will be found to contain about 1134 cubic inches, and as 282 cubic inches make a gallon, so 4 gallons will be equal to 1128 cubic inches, consequently such a barrel will contain and throw out rather more than 4 gallons at every stroke, and supposing this pump to make 10 strokes in a minute, it would yield 40 gallons in a minute, or 60 times that quantity in an hour, and so on. This rule applies in every case, whether the water is sent to a small or great elevation, because the piston cannot move without displacing the water in the barrel, but a small allowance must be made for leakage or waste, because some water will constantly pass the piston and escape, or be otherwise lost and wasted.

This mode of calculation, as before observed, only applies to such pumps as have cylindrical working barrels and pistons, but sometimes pumps are otherwise constructed, of which the fire engine of the late Mr. Bramah, and the excentric pump are instances. In the former of these contrivances, the working barrel instead of being an entire cylinder is a semi-cylinder, and lies horizontally while the place of a piston is supplied by a parallelogram of the same radius and length as the semi-cylinder moving by an iron bar passing through its axis and properly packed at its exterior edges.—This parallelogram is made to vibrate through about 170 degrees by its handles while its outer edges keep in contact with the interior surface and ends of the semi-cylinder, and 2 feeding and 2 delivering valves are placed upon the flat top or covering of the whole. This pump therefore in effect is the same as that of M. de la Hire last described, though quite different in form, and its mode of operation is nearly allied to *The Excentric Pump,* a section of which is shewn at Fig. 102. It consists of a hollow drum or cylinder of metal *a d,* in the interior of which a solid cylinder *b,* of the same length but of only half the diameter or thereabouts, is made to revolve by its axles passing through water tight stuffing boxes in the sides of the larger and exterior cylinder. The internal cylinder does not revolve in the center of the large cylinder, but is so placed that one of its convex exterior edges may come into close contact with some one part of the concave or internal surface of the larger cylinder, as shewn in the figure, and the circular exterior surface of the small cylinder is equipped with 4 metal flaps or valves *c c c c,* turning on hinges, and partaking of its own curvature, so that when they are shut down or closed, they form no projections, but appear as parts of the same cylinder. These flaps are made to open either by springs placed underneath them, or what is still better by two cross wires, sliding through the internal cylinder in such manner that they may cross each other exactly in its center, by which their operation will be rendered equable in every part of their revolution. From the formation of this machine when one of these flaps is brought by the revolution of the internal cylinder between itself and the external one, it will be pressed down close and will shut, but as the inner cylinder moves, it will be carried into a continually widening space until it arrives at *a* opposite to the last mentioned situation, when the cavity formed between it, and the smaller and larger cylinder will have so far increased as to form a vacuum which is filled with water by the feeding pipe *e*. This cavity is no sooner so increased to its largest dimensions than it is diminished by a continuation of the revolution, in consequence of which the water being pent up and squeezed into less compass, makes its escape by the delivering pipe *f*, and as each of the flaps performs the same operation in its turn, this pump affords a very equable and constant supply of water. The greatest difficulty in its construction is, that of keeping the sides of the flaps so packed as to maintain a perfect contact with the sides of the large cylinder without unnecessary friction, a fault which equally holds good in Mr. Bramah's fire engine, in all excentric pumps, and in all the rotatory steam engines that have yet been invented as will hereafter be more particularly noticed. The Excentric Pump is of the lift and force variety, since it will deliver water to an indefinite height above its working cylinders. In order to determine the force or power necessary to work a pump of any description, the height to which the water is to be raised, must always be taken into account, for according to what has been before stated, (page 196) this height multiplied into the area of the piston, and reduced to any of the usual denominations of weight will give the amount of resistance to be overcome, (friction of the pump only excepted.) The size of the pipe containing the water is quite immaterial, as before noticed, provided it be large enough to prevent friction and an unnatural velocity in the water, and the entire perpendicular height from the surface of the water raised to the point where it is delivered, whether occupied by suction or feeding pipe, or delivering pipe from a forcing pump, must be added together and considered as the height of the lift, so that if a lift and force pump of 4 inches diameter in the working barrel has 10 feet of 3 inch suction pipe below its piston, and 20 feet of 2 inch delivering pipe (including the length of the working barrel) about it, the column to be lifted will be equal to 30 feet of 4 inch pipe filled with water. The contents in gallons of 30 feet of 4 inch pipe must therefore be found as before directed, (page 182), and as each gallon of water, weight about 10.2 lbs., the weight or load upon the pump will be immediately found, to which must be added, from 1-tenth to 1-sixth according to the construction of the pump for friction. The load upon an excentric or any other pump may be found by the same rule if the effective horizontal area of the piston, or its substitute be found, and this be in like manner multiplied into the height of the lift.

Independent of the pumps above described there are other machines that raise water by the exertion of certain natural qualities of fluids, such as gravity, centrifugal force, momentum, &c. The Hungarian machine, noticed at page 154, may serve as an instance of the first of these applications, and the centrifugal pump, and the water ram of the second. *The Centrifugal Pump* has several different forms, and after the explanation already given of centrifugal force the principles of their construction will be readily understood. For example, if *g h*, Fig. 103, represent an upright spindle, so fixed, that rapid rotatory motion may be communicated to it by the winch *i*, and *k m* represent any number of curved pipes, each of which contains one valve opening upwards, so disposed and fixed to the spindle, that their lowest ends may be near to it, and be covered by the water to be raised, and their upper ends which are quite open are extended to a considerable distance from the center of motion, and finally bent downwards to prevent the dispersion of the water, such a machine will constitute an effective pump. For if the several curved pipes are filled with water which will be retained in them by their bottom valves, and then be put into rapid motion by turning the winch, the higher ends *m* will describe a much larger circle than the ends below, and consequently such a centrifugal force, or tendency to fly off and empty the pipes, will be induced at the upper ends as will produce a vacuum capable of raising a column of water of considerable height above the reservoir. Any number of pipes may be applied round the spindle to render the pump more powerful, and their lower ends may open into one common water-tight chamber, with a single large valve opening inwards into it to supply and maintain the water for the whole of the pipes, instead of putting a separate valve into each pipe; *l l l* is a circular pan or rim to receive the upper ends of all the pipes and the water they deliver, which runs off by a spout at *n*.

The *Water Ram* or *Belier Hydraulique*, as it was called by its inventor, M. Mongolfier, of Paris, is a highly useful and simple machine, for the purpose of raising water without the expenditure or aid of any other force than that which is produced by the momentum or moving force of a part of the water that is to be raised; and whether its invention arose from accident, or was the result of reasoning, it is one of the most simple and truly philosophical machines that Hydraulics can boast. The effect of this machine depends entirely upon momentum, or the new quantity of force that is generated whenever a body is put into motion, (pages 19 and 40), and the effect of this is so great as to give the apparatus the appearance of acting in defiance to the established laws of Hydrostatic equilibrium; for a moving column of water of small height is made to overcome, and move another column much higher than itself. An operation very similar in effect to the water ram, and which may serve to explain it, is met with in every house in which a supply of water is furnished from a considerably elevated cistern, to an apartment below by means of a descending pipe ending with a cock; both the cock and pipe may be amply strong enough to resist the pressure of the water while in a state of rest, but on opening the cock to permit the water to flow and then suddenly closing it the additional power acquired by such motion will become apparent from the noise and concussion that occurs, which never fails to shake the pipe so as to be sensibly felt, and will even burst it open, if the head of water is sufficiently elevated. This circumstance, it is said, gave rise to the discovery of the water ram,* the form and construction of which is shewn at Fig. 104. Suppose *o* to represent a cistern or reservoir, or the source of a spring which is constantly overflowing and running to waste, by means of a channel a few feet lower than itself as at the level line *p p*. Instead of permitting the water to run over the sides of *o* let it be conducted to the level *p p*, by means of iron or other pipes *q q* connected with the side of the reservoir, and terminating by an orifice *r*, in which a conical or other valve *s* is placed so as to be capable of effectually closing the pipe when such valve is drawn upwards—*t* is an adjustable weight fixed on to the spindle of the valve *s* by means of which the valve is kept down and open; any water therefore that is in the cistern *o* will flow down the pipe *q q*, and escape at the orifice *r*, so long as the valve remains down, but the instant it is raised and shut, all motion of the water is suspended. Thus situated the adjustment of the weight *t* must take place, and by adding or substracting from it, it must be made just so heavy as to be capable of sinking or forcing its way downwards, against the upward pressure of the water, the force of which will depend upon the perpendicular distance from the surface of the water in *o* to its point of discharge at *r*, (represented by the length of the dotted line *o v*,) consequently if the valve *t* be raised by the hand or otherwise, all motion of the water in the pipe *q q* will cease, but the instant the valve is released, it will fall down and permit the water to escape. The water by moving acquires momentum and new force, and consequently is no longer equal to the column *o v* to which the valve has been adjusted, but is superior to it, by which it is enabled to overpower the resistance of the weight *t*, and it carries the valve up with it, and closes the orifice *r*. This is no sooner done than the water is constrained to become stationary again, by which the momentum is lost, and the valve and weight once more become superior, and fall, thus re-opening the orifice and permitting the water to move again, and as the pressure of the water and the weight of the valve each become alternately superior, the valve is kept in a constant state of vibration, or of opening and shutting without any external aid whatever. Such is the principle upon which the motion of the water in the pipe *q q* is produced, but the momentum generated cannot be instantly annihilated, and it is not only of sufficient power to raise the valve *s* but likewise to burst open the lower end of the pipe *q q*, unless a sufficient vent be provided by which this accumulated force can escape. Accordingly a second valve *u* is placed near the lower end of these pipes, and is made to open upwards into an air vessel *w* with a discharging pipe *x*, arranged as before described in speaking of the force pumps, and consequently whenever the valve *s* is closed the water which otherwise would have flowed from the orifice *r* now opens the valve *u* and enters the air vessel, until the spring of the contained air overcomes the gradually decreasing force of the momentum, when the valve *u* closes and that at *s* opens to permit the water to make a second blow or pulsation, and in this way the action of the machine continues unceasingly without any external aid so long as it is supplied with water and remains in repair. A small running stream is necessary for this machine, as the water at *o* should be kept at one constant elevation to insure the perfection of its action. A much greater quantity of water likewise escapes at the orifice *r* between the pulsations than can be raised in the delivering pipe *x*, particularly if it extends to any considerable height, for the comparative quantity of water discharged through *x*, and permitted to run to waste at *r*, must always depend upon the respective perpendicular heights of the pressing column *o v*, and the delivered or resisting column *w x*, and the rapidity of the pulsations will likewise depend on the same circumstances. A very insignificant pressing column *o v* is capable of raising a very high ascending column *w x*, so that a sufficient fall of water may be obtained in almost every running brook, by damming up the upper end to produce the reservior *o*, and carrying the pipes *q q* down the natural channel of the stream until a sufficient fall be obtained, for the greater the length of the descending pipes from *o* to *r*, and the more certain will be the effect of the machine since if the column *q q* is not of sufficient length its water will be thrown back into the reservoir instead of entering the air vessel. The author has constructed several of these machines with great satisfaction in different parts of England, and in order to show their efficacy subjoins the following particulars of one which has been in constant use for about 2 years.—The reservoir *o* is a bason of about 10 feet square and 2 feet deep, formed partly in limestone rock and partly in brickwork, the supply of water being from a natural spring. The pipe *q q* is of cast iron, 14 yards long and 2 inches diameter. The piece at the end containing the valves and air vessel is about 15 inches long. The valves 1½ in. diameter each, and made of brass. Contents of the air vessel about 1 gallon, the height from the surface of the water at *o* to its point of discharge at *r*, is 6 feet 4 inches measured perpendicularly. The delivering pipe *x* is of lead 1 inch diameter, and proceeds horizontally under ground for about 104 feet, and then rises perpendicularly to the height of 54 feet 3 inches above the discharging valve at *r*, where it delivers the water into a large cistern. The water is thus raised 47 feet 11 inches above the surface of the spring that supplies it, and this by a fall of only 6 feet 4 inches. So circumstanced the valve *s* makes 50 vibrations or opens 50 times in a minute when it loses about 2 quarts of water, and injects nearly a quarter of a pint into the elevated cistern at each pulsation, the water lost being to that raised very nearly as 17 to 1. This may appear a small quantity of water, but when it is recollected that the machine is constantly at work by night and by day, (unless purposely stopped,) and furnishes 6 quarts of water every minute, this will be found to be a supply adequate to a very large household establishment.

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* Quarterly Journal of Science and the Arts, Vol. I. p. 211.

In another instance a machine of similar dimensions furnished 7 quarts per minute to a reservoir at 28 feet 6 inches above the water ram, the fall in the pipes *q q* being 6 feet.

This simple and elegant machine has been long known in England, though but little used. Mr. Mathew Boulton, of Soho, near Birmingham, obtained a patent for it in 1797,* and a water ram of considerable dimensions was constructed at the same time for supplying his house with water. The machine was however not found to answer as at first constructed, or indeed as above described, because from the mutual incorporation that takes place between air and water, (page 113), the successive quantities of water that were impelled into the air vessel, absorbed the whole of the air which it contained, and it became quite filled with water and ceased to afford that elasticity which is indispensible to the working of the machine. This was also discovered by M. Mongolfier in France, who, in 1816, obtained an English patent for his improvement of this machine, by introducing a very small snifting valve, opening inwards into the lower part of the air-vessel, but kept shut by a small spring. This valve is self-acting, and effectually prevents the escape of any air or water from the air-vessel, but when the water is thrown back by the shutting of the valve *s* Fig. 104, it produces an instantaneous vacuum at the extreme end of the pipe *q*, upon which the snifting valve opens, and admits of a sufficient quantity of the external air into the air vessel to keep it constantly replenished, and by this simple addition is the water ram rendered continuous in its action. Unfortunately for M. Mongonfier his English patent is an unavailing one, since he had permitted all the particulars of his improvements to be published in the *Annales des Arts, &c.* in France, and the account was translated and presented to the British public in one of our periodical Journals,* above three years before he attempted to obtain his exclusive privilege. The same defect exists in all pumps and engines to which an air vessel is applied, particularly when the air is subjected to great pressure, and therefore a small orifice capable of being closed or adjusted by a cock or screw valve, should be made in the suction or feeding pipe of every forcing pump that is connected with an air vessel, in order to enable the pump to draw in and deliver as much air into the air vessel as will exactly counteract the absorption, and which will readily be determined by experiment.

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* See Repertory of Arts, Vol. IX. p. 145, First Series, where the specification is given at length.

Hydraulics not only contemplates the construction and action of machines for raising water above its level, such as those that have been last described, but likewise the means by which motion and power may be obtained from the motion and other properties of fluids. Accordingly a brief examination of the various mill or water wheels and other contrivances by which motion is given to machinery must form the conclusion of the present section.

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* Repertory of Arts, Second Series, Vol. XXXIII. p. 315.

Motion is generally obtained from water, either by exposing obstacles to the action of its current, or by arresting its progress in moveable buckets or receptacles which retain it during a part of the progress of its descent. Thus, if we suppose the action of the wheel shewn at Fig. 92, to be the reverse of what it has been described to be, viz. that instead of the buckets *n o p* receiving their water from the stream *r r*, and delivering it into the elevated cistern *s*, we imagine the cistern *s* to be supplied by the stream, and that the several buckets *o o o n* shall become filled with water instead of emptied by passing the cistern *s*, the side *o o o* of the wheel will become heavier by the weight of all the water that the buckets contain, than the opposite side *q q q* in which the buckets are supposed to remain empty. The consequence of this will be that the wheel will revolve in the direction of the letters *p o n*, and if the buckets *q q* are filled as they get to the top, and those at *n n* emptied by some contrivance when they reach the bottom, the motion of such a wheel will be continuous, and it will revolve with a force and velocity dependent on the weight of the buckets of water, their distance from the center, and the velocity with which they are filled: in fact, such an arrangement is a very close approximation to what is called the over-shot water wheel which will be presently described.

Water wheels have three denominations, depending on their own particular construction, on the manner in which they are set or used, and upon the manner in which the water is made to act upon them, but all water wheels consist in common of a hollow cylinder or drum revolving on a central axle or spindle from which the power to be used is communicated, while their exterior surface is covered with vanes, float boats, or cavities, upon which the water is to act. Thus Fig. 105 is a side view of an under-shot, tide, or stream wheel, which was the most common and is by far the oldest construction in use. As this kind of wheel requires no other fall in the water than that which is necessary to produce a rapid progressive motion in it, and as it acts chiefly by the momentum of the water, its positive weight being scarcely called at all into action, it is only fit to be used when there is a profusion of water always in motion. It has however the advantage of being the cheapest of all water wheels, and as it does not require a very considerable fall of water, it is more applicable to rivers in their natural state than any other form. On this account it has probably been chosen for the wheels of the water works under London Bridge. It likewise works equally well whether the water acts upon the one or the other side of its float boards, which renders it particularly applicable to tide rivers, where the current is sometimes running in one direction, and at others in an opposite course. There are however some practical disadvantages attendent upon this form of wheel, particularly when made of small diameter, for if the float boards stand radiantly round it, or pointing to the center, as *a b c d e* in Fig. 105, although the three central floats *b c d* stand in good positions, to produce the greatest effect, being all nearly at right angles to the direction in which the water moves, yet the float *a* enters the water so obliquely as to meet with great resistance to its passage at the same time that the retiring float *e* leaves the water under circumstances that are equally disadvantageous, and is obliged to plough or throw up a portion of water before it, which tends very materially to retard the motion and impede the power. This appears to be partly obviated by giving the float boards a different figure, or placing them so as not to point to the center of the wheel, as shewn at Fig. 106. In this case, the ascending float board *f* is nearly at right angles to the water at the time of leaving it, and rises almost perpendicularly out of it, being thus placed in a much more beneficial position than in the last figure. But, although the retiring float is thus improved, the entering one *g* is much more disadvantageously placed, for now it will come down almost parallel to the surface of the water, and thus the advantage that is gained at one side of the wheel is lost at the other. It does however appear that there is a small practical advantage in giving the float boards a slight inclination from the center, but it must not be carried by any means so far as shewn at Fig. 106.

As action and reaction are always equal, but in contrary directions, of course it is the same thing whether the power of the moving water be applied to the float boards of a wheel which revolves in a fixed building, or whether any extraneous force be applied to the axis of a wheel to cause it to move in still water: in the first case the power of the water will be transferred to the axle of the wheel, and is applicable to the driving or moving of machinery; while in the second case the power applied to the axle will be resisted by the quiescent water, and will be converted into so much power for moving the building or boat in which the wheel is placed, and upon this principle depends the action of those steam boats which are impelled through the water by means of water wheels driven round by the power of steam engines applied to their axles, instead of permitting the water to move the float boards and transfer its power to the axis.

Whenever the weight and motion of water can be made use of, as well as its momentum much greater effects can be produced than the last described machine is capable of, and with a much less lavish expenditure of the fluid, for then its utmost powers of action are brought into play at once, and accordingly those water wheels that are distinguished by the

page 201 to 221

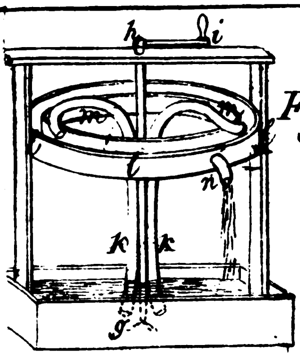


Fig 103.

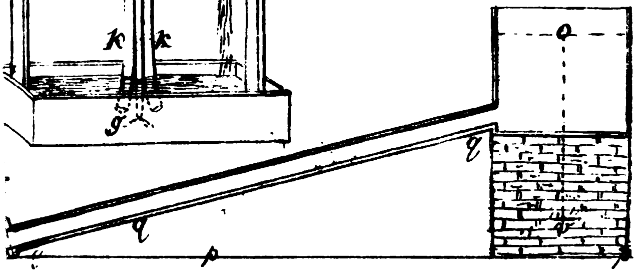


Fig. 106

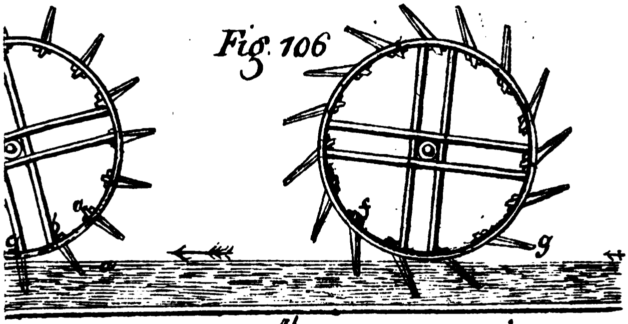
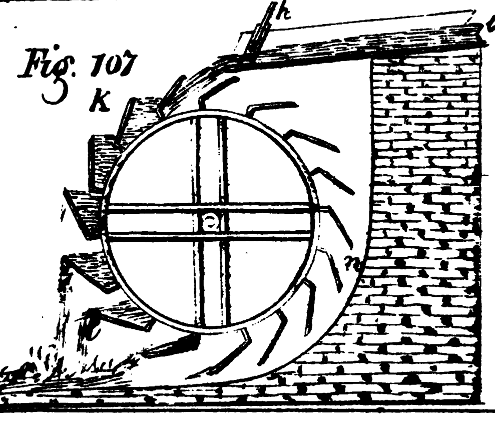


Fig. 107



names of breast-wheels, and over-shot wheels will produce much greater power with a much less supply of water than the under-shot wheel already described. Both these wheels however require a considerable fall in the stream upon which they are placed, and consequently destroy it for the purposes of navigation, unless that ingenious Hydraulic contrivance the *Pound Lock* be resorted to, by means of which barges or vessels of any magnitude may be transported from one level to another without difficulty, and with very little loss of time. *The over-shot Water-Wheel*, which of all others gives the greatest power with the least expence of water, requires a fall in the stream equal to rather more than its own diameter, therefore it is customary to give this description of wheel a greater length in proportion to its height than is give to any other, by which an equality of power is obtained. In the construction of the over-shot wheel a hollow cylinder or drum that is impervious to water is first prepared, and hung upon a proper central axis. A number of narrow troughs or cells generally formed of thin plates of metal extending from one end of the drum to the other are next fixed round the outside of the wheel so as to give a transverse section through the middle of the wheel, the appearance shewn at Fig. 107.— The water is conduced by a level trough of the same width as the wheel over its top as at *h i*, and is discharged into the buckets or cells placed round the wheel to receive it, as at *k l*; from the particular form of these buckets they retain the water thus thrown into them, until by their motion they descend towards the point *l*, when their mouths being turned downwards they discharge their contents into the tail stream *m* where the water runs to waste. The buckets on the opposite side *n* of the wheel descend with their mouths downwards, and thus remain empty until they arrive under the end *k* of the water trough to be refilled; at *k* then is a penstock or sluice for regulating the quantity of water and preventing waste, since if the water was permitted to flow too rapidly it would splash out of the buckets near *k* instead of filling them, and would run down over the surface of the wheel without producing its proper effect. To prevent this the water is seldom permitted to run upon the wheel in a stream of more than from half an inch to an inch in thickness, and when well regulated there is scarcely a drop of the water ineffectually wasted. In calculating the power of the overshot wheel it was customary before the time of Mr. Smeaton to make some allowance for the momentum of the water falling into the buckets, but this he has shewn must not be taken into account, for if the water falls too rapidly or from too great a height, it not only splashes out of the buckets, but carries a quantity of air and foam down into them, which prevents their becoming properly loaded. The over-shot wheel therefore acts by the gravity or weight of the water contained in the buckets for nearly 1-third of its circumference, and from the experiments of Mr. Smeaton which were made with great accuracy it appears that the dimensions, quantity of water, and height of fall being the same, the over-shot wheel will produce double the effect of the under-shot.

The Breast Wheel is by far the most common; and may be considered as a mean between the two varieties before mentioned. In this, the water instead of passing over the top of the wheel, or entirely beneath it, is delivered about half way up it, or rather below the level of the axis, and the race or brickwork upon which the water descends is built in a circular form, having the same common center with the wheel itself, so as to make it parallel to the exterior edges of the flat boards or extreme circumference of the wheel.—This construction is shewn at Fig. 108, Plate X. where *o p q* is a side view of a wheel, formed with float boards in the same manner as the under-shot wheel, but instead of the water acting upon its lower part *q* it is introduced upon it at *p*, by the sluice or penstock *r*, which, by rising or falling, permits a greater or less quantity of water to act on the wheel, and as the float boards are made to fit as accurately as possible without contact, into the circular hollow *s t* of brickwork, no water can escape past the wheel without producing its proportionate effect.

Mr. Smeaton makes no observations on the nature of Breast Wheels in his valuable Papers,* except to state that all wheels by which the water is prevented from descending, unless the wheel moves therewith, are to be considered of the nature of over-shot wheels, having power in proportion to the perpendicular height from which the water descends; while all those that receive the impulse or shock of the water, whether in an horizontal, perpendicular, or oblique direction, are to be considered as under-shots. The breast wheel is of this first description, for notwithstanding it has only float boards instead of buckets, yet as the mill course is made concentric to the outside of the wheel, and is not only there, but at the two sides, made as close as convenient, so as to prevent the escape of water as effectually as possible, the spaces between one float board and another become buckets for the time being and retain the water, and thus the breast wheel is not only impelled by the weight of water, but by its impetus or momentum also, for the water is so confined as to be incapable of splashing or being lost, and consequently its moving force may be exerted to great advantage. Notwithstanding this apparent superiority, still the breast wheel is in effect vastly inferior to the over-shot wheel, not only on account of the smaller height at which the water is supplied, but from the waste with which it must always be attended, even under circumstances of the most perfect workmanship. When well constructed and closely built in, its effect, according to Mr. Smeaton, should be the same as an under-shot wheel, whose head of water is equal to the difference of level between the surface of the stream and the point where it strikes the wheel, added to the effect of an over-shot wheel, whose height is equal to the distance from the striking point, to the tail water of the mill, or that which runs to waste. This is however on the presumption that the wheel receives the impulse of the water at right angles to its radii, and that every thing is constructed to the best advantage. In practice it is found that the breast wheel just consumes about double the quantity of water that the over-shot wheel requires to do the same quantity of work, when all things are alike, that is to say, the diameter and breadth of the wheel, number of float boards, &c. though from theory and calculation it should do rather more, for Lambert and others who have written on this subject attempt to demonstrate, that the power of the over-shot to that of the breast wheel is as 13 to 5, but this is upon a supposition that no water escapes ineffectually which is utterly impossible in practice.

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* **Experimental Enquiry concerning the natural powers of Wind and Water to turn Mills and other Machines, by John Smeaton, F.R.S 1 vol. 8vo. London, 1796.**

In order to permit any of the above wheels to work with freedom, and to the greatest advantage, it is absolutely necessary that the tail water, as it is called, or that which is discharged from the bottom of the wheel after it has produced its effect, should have an uninterrupted passage to run away, for whenever this is not the case, it accumulates, and forms a resistance to the passage of the float boards, and consequently abstracts considerably from the velocity and power of the wheel, sometimes indeed to so great an extent as to prevent its working altogether. One of the simplest and most effectual means of removing this inconvenience is by an expedient not much known or practised, and which consists of forming two drains or tunnels through the brickwork or masonry at each side of the water wheel, whatever may be its construction, so as to permit a portion of the upper water to flow down into the tail or lower stream immediately in front of the wheel. The water thus brought down with great impetuosity drives the tail water before it, in such a manner as to form a bason or hollow place, in which the wheel can work free from interruption, even if the natural state of the water were such as might produce a tailing of from 12 to 18 inches without this assistance. And since the tailing of mill streams only occurs in the winter seasons, or at times when there is a profusion of water, so the quantity that is thus thrown away without operating upon the wheel can be spared without inconvenience. Each of the drains or tunnels is furnished with a sluice gate or penstock at its upper end, by which the quantity and impetus of the water can be regulated at pleasure, or the whole be shut off whenever water happens to be scarce.

The three varieties of water wheels already noticed are the only ones generally admitted into practice, and they do not admit of much improvement since their principles must always remain the same. The over-shot wheel has perhaps been brought nearer to perfection than any of the others by the contrivance of Peter Nouaille, Esq. who in a mill that he has near Seven-Oaks, in Kent, has caused the water to revert back again from the top of the wheel, instead of passing over it, and in this way a much greater portion of the circumference of wheel is brought into action than is generally the case.*

There is another machine for the purpose of procuring motion and power by water, which was invented by a Dr. Barker towards the close of the last century, and which is generally known by the name of *Barker's Centrifugal Mill.* In this the water does not act by its weight or momentum but its centrifugal force, and the resistance that it meets with in passing through the air. Its general construction is shewn at Fig. 109, in which *v u* is a metal pipe of considerable height, its top *v* being widened or extended into a funnel shape. The pipe is maintained in its vertical position, as shewn in the figure, by resting on a pointed steel pivot turning into a brass box *w* at the lower extremity, while the upper part has a cylindrical steel axis passing through the top *y y* of a frame which supports it: the pipe *v u* is consequently free to move round upon its own axis, which it does with very little friction. Towards the lower extremity of the pipe *v u*, and at right angles to its axis, two or more smaller pipes or arms with closed exernal ends are inserted as at *z a*, and an adjustable orifice is made at the side of each of these small pipes as near as possible to its end, and placed on opposite sides of such pipes, so that water issuing from them may spout horizontally and in opposite directions, as shewn at the letters *z* and *a*. One end of a pipe *b* communicates with a supply of water which it delivers into the funnel head *v* without touching it in any part, and the supply of this pipe must be so regulated by a cock or otherwise, that it may constantly keep the pipe *u v* filled with water without running over, at the same time that the discharge is going on from the orifices *z a*, which will deliver their water with a force proportionate to the perpendicular height of the column of water contained in *u v*, and since the holes *z a* are in opposite directions, the water in passing from them will meet with such a resistance from the surrounding air as to throw the pipe *u v*, with its arms aad axis *x*, into rapid rotatory motion, and this axis may communicate its motion and power to wheelwork or machinery, or even to a mill-stone connected with its upper end. This machine is described and highly spoken of in almost all the books that treat of Hydraulic machinery, but it does not appear to have been carried into practical effect in England. Dr. Desaguliers mentions it in high terms of commendation, as does Euler, who enters into an elaborate description of its theory and importance in the memoirs of the Academy of Berlin for 1751, and agrees with Bernouilli, at the close of his Hydraulics, in saying that, it excels all other methods of employing the force of water to obtain motion. The power of this machine does not depend altogether on the perpendicular height of the water in the pipe *u v*, but on the centrifugal force that is generated in the arms *z a*, by which a much more rapid and violent discharge of the water takes place than would occur from the elevation of head alone, and by which a proportionate velocity of motion is also produced. In Rozier's Journal de Physique, August 1775, there is an account of an improvement of this machine by M. Mathon de la Cour, in which the water is made to ascend instead of descend into the pipe *u v*, by means of a close ground joint: in this way any height of water can be conducted by close pipes to operate on the machine without increasing the height and consequent weight of the revolving pipe, which makes the machine much more compact and free from friction. Mr. Waring describes a machine of this description, on M. Mathon de la Cour's construction, from his own inspection in the 3d vol. of the Transactions of the American Philosophical Society, and of which he gives the following dimensions. The radius of the arms from the center pivot to the center of the discharging holes 46 inches; inside diameter of the arms 3 inches; diameter of the supplying pipe 2 inches; height of the working head of water 21 feet above the points of discharge. This, though a great fall, evidently a very small consumption of water, since it was all supplied by a 2-inch pipe, and when the machine was not loaded, and had but one discharging orifice open, it made 115 turns in a minute. This gives a velocity of 46 feet in a second for the orifice of discharge, which is 9 feet and 5-sixths in a second faster than the water would flow out under the simple pressure of a 21 feet head, which great excess of velocity can only be attributed to the prodigious centrifugal force generated in the arms, and upon which this machine in a great measure depends for its action.* Barker's mill is a machine, which is very warmly recommended to practice by all the eminent mechanics who have investigated the subject, and considering the high respectability of their names, and the simplicity and cheapness of the machine, it cannot but be matter of surprise that no attempts at its construction on a large scale have been made in Great Britain, where the motive power of water has been more extensively used than in any other part of the world, and has in no small degree contributed to that pre-eminent excellence which our country is acknowledged to have obtained in her various manufacturing processes. The application of water to the driving of machinery is so simple, so cheap, and so constant, and equable in its action, that it amply merits the preference constantly shewn to it whenever it can be obtained: but it very frequently happens, that motion and power are required for machinery, where no running stream can be found, and where, if animal labour could be procured, it might either be too expensive, or incompatible with the local circumstances of the place; and then that pride of British invention *The Steam Engine* stands forth conspicuously useful. The Steam Engine, though described in this place, cannot with propriety be called an Hydraulic Engine, because its construction depends more upon Pneumatic than Hydraulic principles, inasmuch as the water to impel it is not used in its natural state, but is previously converted into steam by the application of heat; and the steam thus produced is an highly elastic vapour, invisible while unmixed with air, and capable of being conducted through tubes, and acting upon valves, pistons, or other resistances in the same way that condensed air does.

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* For other improvements or variations in the form and construction of Water Wheels, see the contrivances of Mr. Besant, Mr. Smart, Mr. Perkins, &c. in the Transactions of the Society for the encouragement of Arts, Manufactures, and Commerce.

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* For further particulars of Barker's Mill, and a minute investigation of its powers, see Dr. Gregory's Mechanics, Vol. II. page 113. Third Edition, 1815.

The manner in which caloric or the matter of heat acts upon all bodies, to enlarge their dimensions by setting their constituent particles at greater distances from each other, has been already explained, page 14. If on this principle solid ice be considered as the natural and simple state of water, the addition of a certain quantity of caloric to it will so far separate its particles as to overcome their cohesion, and cause it to flow or assume the common fluid character of water; and continuing the addition of heat will still further alter the character of the water, and by setting its particles at still greater distances asunder will convert it into steam; for experiment has proved, that a single cubic inch of water, when heated to 212 degrees Fahrenheit, for a sufficient time to boil it all away, will produce nearly 2000 cubic inches of steam, and if this steam, instead of being permitted to escape into the air, be received in a close vessel, and again heated to above 212 degrees both its bulk and elasticity may be astonishingly increased.

Evaporation, or the production of steam, is constantly going on from all fluids at all temperatures, but in the ordinary heat of the atmosphere it proceeds slowly and invisibly. If however that heat be increased by any means to about 212 degrees, then steam is rapidly and visibly formed throughout every part of the fluid, and the expanded bubbles rising from the lower to the upper parts cause that motion or ebullition in the fluid, which is generally understood by boiling, and which effect takes place under the ordinary pressure of the atmosphere at 212 degrees Fahrenheit, although it has been shewn, page 111, that when that pressure is diminished the same appearance of boiling takes place at a much lower temperature, and on the contrary if water be made to boil under greater pressure, (condensed air for example or the pressure of its own steam when not suffered to escape,) then the ebulition or boiling does not take place without an increase of heat over and above the 212 degrees, which is always proproportionate to the force acting upon the surface of the water.

From this we learn that the boiling point of fluids is by no means fixed, but will depend upon the circumstances under which they are heated, and in assuming 212 degress of Fahrenheit, to be the boiling point of pure water it must be understood to be so, when the barometer stands at 30 inches; for when the quicksilver falls below this height, water will require less heat to make it boil, and the necessary heat will increase with the increasing height of the barometer. The steam produced thus becomes an exact balance to the pressure exerted upon the water, so that when water boils with 212 degrees, and the barometer stands at 30 inches, the steam that it produces will be just equal in power to the pressure of the atmosphere on the outside of the boiler, presuming it to be a close one, but if the steam be not permitted to escape, it will very rapidly accumulate, and increase in power until at length the boiler may be burst open by its force. During this accumulation, the water will however increase in heat above 212 degrees, as may be ascertained by keeping a thermometer immersed in it. Steam as above described, which is equal in force to about 14½ lbs. on the square inch, or the ordinary pressure of the atmosphere is frequently called Atmospheric Steam, or Steam of one Atmosphere, but when of double or triple this force is designated Steam of 2 or 3 Atmospheres, and so on, and from experiments that have been made on steam, it appears that its elastic force may be multiplied, perhaps infinitely, if the heat be sufficiently augmented, since it has been found capable under such circumstances of bursting every vessel by which it has been attempted to be confined.

The most convenient apparatus for trying experiments upon steam on a small scale is shewn in section at Plate X. Fig. 110. It consists of a strong hollow copper or brass ball *a*, about 4 inches in diameter, supported by a stand which admits a spirit or other powerful lamp to be placed under it for heating the water. On the upper part of the ball are four orifices; in the central one *b* an upright glass barometer tube of 30 or 40 inches long, and with an open top and bottom, is fixed by an air-tight screw cap, while the lower end of the tube dips into a small open-topped reservoir within the ball, containing just quicksilver enough to fill the tube. A mercurial thermometer is fixed by a similar cap *c* to the second orifice. The third *d* has a conical safely valve opening outwards, but which may be held down in a greater or less degree by an adjustable spring, and the fourth *e* is furnished with a stopcock for the purpose of exhausting the ball of its air, or permitting the sudden escape of its steam, or conveying it away by a pipe for any experimental purpose: *f f* is a scale graduated to inches and tenths for observing the rise of the mercury. With such an apparatus the heat of water and its corresponding strength of steam can be very accurately measured, for the thermometer measures the one while the steam pressing on the surface of the quicksilver, and forcing it up the glass tube indicates the other by the height to which it ascends, as measured upon the scale *f f*, and by experimenta researches made in this way, by M. Bettancourt, and afterwards rendered more correct by Mr. Dalton, and by others it has been determined that the force of the confined steam of water corresponding with different degrees of temperature is very nearly as expressed in the following table :—

Table of the Strength of the Vapour of Water, in Terms of Atmospheric Pressure, at different Temperatures, according to Fahrenheit's Thermometer.

Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.	Temperature.	Pressure.
50	.006	120	.099	182	.500	245	2.00
60	.011	130	.130	190	.601	250	2.50
70	.017	140	.172	200	.760	261	2.75
80	.027	150	.225	212	1.00	268	3.00
90	.040	160	.287	221	1.22	275	3.35
100	.054	170	.371	230	1.48	279	3.50
110	.075	180	.465	239	1.80	312	6.50

In the above table, which only shows the comparative force of steam, the common or ordinary pressure of the atmosphere, is assumed to be 1.00 for the sake of simplicity, and because in speaking of steam or condensed air it is usual to compare it with atmospheric pressure; and since it has been found that steam of the temperature of 212 degrees is just a balance to the ordinary pressure of the atmosphere the term 1.00 stands opposite to that temperature to indicate that steam of that heat is equivalent to one atmosphere without a fraction. But if we take the temperature of 230 degrees then 1.48 stands against it, indicating that when the heat is so raised the pressure of the steam will be equal to one atmosphere and 48 hundredths, or very near an atmosphere and a half, while at 245 degrees it becomes equal to two, and at 268 to three atmospheres. It thus appears that equal increments of heat do not produce proportional increments in the force of steam, for it requires no less than 182 degrees of temperature to produce a strength of steam equal to 0.500 or half the pressure of the atmosphere, while the addition of only 30 degrees of heat making 212 degrees produces double the force or 1.00, and a further addition of but 56 degrees by raising the temperature to 268 degrees increases its first power six fold, or makes it equal to three atmospheres.

The pressure exerted by steam upon a boiler can be readily found by the table for any temperature within its limits, or on the contrary, if the pressure be known, the temperature of the water can be ascertained; for since the ordinary pressure of the atmosphere is equal to 14¾lbs. or 14.75, so by multiplying the pressure found in the table for any given temperature by 14.75, the result will be the force exerted by the steam in pounds avoirdupoise against every square inch of surface in the boiler presuming it to be surrounded by a vacuum. But since this can never occur in nature, where boilers are surrounded by the external air, so 14.75lbs. must be substracted from the product of the multiplication, and the remainder will be the actual effective force that remains for the boiler to support. Thus for example, steam at 212 degrees produces no strain or force against a boiler, and if we multiply its representative number 1.00 by 14.75 the product will be 14.75lbs. which is the pressure that would be exerted upon every square inch of the boiler to burst it if it were surrounded by a vacuum; but since it is surrounded by air, and that air presses with a force of 14.75lbs. upon every square inch against the steam, the substraction of this pressure from the first leaves no residue, and shews that no pressure exists. But if we take the temperature of 279 degrees its equivalent number in pressure is 3.50, and this multiplied by 14.75 gives a result of 51.625lbs. for the presure upon every square inch in vacuo, and deducting 14.75lbs.

leaves 36.87 lbs. for the actual pressure that would be exerted by the steam upon every square inch of surface of a boiler surrounded by air. The number of square or superficial inches contained in the entire surface of any boiler can easily be ascertained, and this being multiplied by the pressure upon a single inch (found as aforesaid) will give the amount of the effective force which exists to burst or separate the parts of such a boiler, which ought in all cases to have a strength equal to at least three times the force it is intended to resist.

In like manner, if the force exerted by steam is known, the temperature of the water producing it can be determined by reversing the above operation, for whenever steam is found equal to two atmospheres or 29½ lbs. on the square inch, its temperature must be 245 degrees, and so on for other pressures. In making experiments upon steam it is always best to judge of the state of its expansion by a mercurial guage, though the same thing can be done by valves properly loaded, as will be hereafter explained. In the instrument shewn at Fig. 110, the steam generated in the hollow ball *a* will press on the surface of the quicksilver in the small reservoir, and press it up the tube *ff*. But since steam at 212 degrees is balanced by atmospheric pressure, and the tube *ff* is open at its top, the quicksilver cannot begin to rise until that temperature is increased, and as atmospheric pressure is very nearly equal to 15 lbs. on the square inch, and is balanced by about 30 inches of quicksilver in the barometer tube, (p. 102,) it follows that each 2 inches of rise of the quicksilver in a tube like *f f* must be equal to 1 lb. of pressure or elastic force in the steam, and consequently a mercurial guage, when consulted in conjunction with a barometer, becomes a most accurate, and is a very sensible test for the strength of steam, and such a guage generally is, and ought always to be applied to the boilers of all steam engines, or other vessels for generating steam in order that the state of the confined steam may be accurately known. The guage usually applied to engine boilers is of the syphon kind, and consists of an iron tube bent into the form shewn at Fig. 111, and open at both its ends; *g h* is the tube, and *i* a small plate or flanch, by which it is fixed to the upper part of the boiler, or to any pipe that communicates with the steam. The lower part of this tube is filled with quicksilver as from *g* to *h*, and a slender stick *k* is introduced into the part *h* of the tube so as to float on the surface of the quicksilver as it rises and falls, consequently the upper end of the stick will point out any variation of height in the quicksilver upon the scale *l l*, which is graduated into inches and half inches. When no steam is operating on this instrument, the mercury will fall to the same level in both the legs of the guage, and the top of the stick will be level with the bottom of the scale or top of the tube *h*, but whenever steam enters at the orifice *i* it will press on the surface of the quicksilver at *g* and elevate that at *h*, together with the stick, and thus point out the force of the steam. One inch upon this scale is equal to two inches or a pound of pressure in a straight tube, for the reason already explained in speaking of the syphon guage for the air pump, at page 106.

Having thus shewn how the force of steam may be measured, the necessity of such measurements must be evident, when it has been ascertained that no vessel however strong is capable of withstanding its violence, provided the heat be sufficiently increased.—Of this we have many melancholy instances among which may be recorded the fatal catastrophe that occurred in November 1815, at the sugar-house of Mr. Constant, near Wellclose-square, London, where the explosion of a steam boiler not only destroyed several lives, but completely annihilated the premises in which it was situated, and did great damage to the adjoining houses. The explosion of the steam engine boiler on board the Norwich steamboat is another and more recent accident of the same kind, the catalogue of which might be much increased were not the recollection of them so painful, that it is deemed better to consign them as far as possible to oblivion.

To form a tolerably just estimate of the immense expansive power of steam, and its violence when confined, an experiment may be tried on so small a scale as to be unattended with danger, by means of what is called a candle cracker. This consists of a small bulb, blown in glass to about the size of a pea, but with a neck left to it of about three quarters of an inch long. The bulb is half filled with spirits of wine, and then hermetically sealed with a blow-pipe. Upon sticking the neck of one of these bulbs so prepared into a candle in such manner that the bulb may stand upwards, and be rather less than a quarter of an inch from the flame, the inclosed spirit will soon boil and be converted into vapour, which being unable to escape will accumulate, and will speedily burst the glass bulb with a report like that of a pistol, and with such force that the wick and top of the candle will be violently depressed and the glass dispersed in all directions. To perform this experiment with perfect safety, the wick of the candle should be opened and spread, but not lighted when the cracker is placed in it, when it may be placed under a table or behind a screen and then lighted, which allows time to retreat before the spirits can possibly boil, and thus the eyes and skin are protected from the splinters of glass that are thrown in every direction with the utmost violence.

The force of steam can also be pleasingly illustrated by the instrument called the *Œlipile*, the general form of which is given at Fig. 112. It consists of a small metal vessel *m*, equipped with a spring safety valve at *n*, and a pipe or neck proceeding from the upper part of the vessel, and terminating in a very small orifice at *o*. A spirit lamp is applied at *p* to boil the spirits of wine or water with which the vessel *m* is about half filled, and since from the situation of the pipe this fluid cannot escape, its steam alone will come over, and this will rush from the orifice *o* with a force dependent on the heat of the lamp, and generally with such violence as to have the appearance, and make the noise of the blowing of wind: *q q* is a frame for supporting the vessel *m* at a proper height above the lamp *p* in order to regulate the heat, and sometimes this frame is mounted upon wheels *r r r*, when the force of the steam issuing from *o* will meet with such resistance from the surrounding air as to cause the whole machine to run backwards, or in a direction opposite to that in which the steam issues, thus producing motion by the agency of steam, but not with sufficient power to be applied to any beneficial purpose. The principal use of the Œlipile is to act as a blow-pipe or pair of bellows, for if the current of steam be directed through the flame of a lamp placed near *o*, it will answer every purpose of a blow-pipe, even though the vapour of water be made use of, for the steam may be so highly attenuated by the lamp *p* that the few aqueous particles it contains will not at all interfere with the heat of the flame through which it passes. When constructed on a larger scale it may be made to blow a fire upon which the instrument is placed, or one that is detached as most convenient. The safety valve at *n* is to guard against any accidents that might arise from the orifice *o* becoming choaked by any accidental cause.

One of the earliest attempts that we find recorded of the means of obtaining motion and disposable power for machinery from steam was by one Brancas, an Italian, who proposed an Œlipile on a large scale, and the application of a wheel equipped with sails or vanes, like the water-wheel shewn at Fig. 105, to it. These vanes coming in succession by the motion of the wheel before the orifice of the tube would be forcibly blown round. This was a kind of windmill operated upon by steam, but it does not appear to have been carried into effect with any particular success nor indeed was it until the condensation of steam was made use of as well as its elastic force, that any thing like a steam engine could be said to be constructed.

By condensation of steam we are not to understand, the forcing or compressing it into less compass, as explained when treating of air, (page 114,) but the actual reconversion of it into water again. The difference between a gass or air and steam has already been explained, page 90, as well as why the one is called, a permanently elastic, and the other simply, an elastic fluid, for air retains its elasticity under all changes of temperature which is not the case with steam, for the instant that steam comes in contact with any thing colder than the boiling point of the fluid from which it is produced it looses its elasticity, and becomes reconverted into the state of tangible fluid, and should the difference of temperature be very great, this change takes place with astonishing rapidity. If therefore instead of presenting the flame of a lamp to the orifice *o* of the Œlipile, Fig. 112, a plate of cold iron is substituted, the force of the steam will instantly disappear, and the plate will shortly be covered with drops of water which will trickle down its surface until the plate itself becomes too hot to produce condensation which will soon be the case, for that heat which lately existed in the steam must be transferred to the plate or elsewhere, before condensation can possibly take place.

The nature of steam, and the difference that exists between it, and the gasses or permanently elastic fluids is rather an object of chemical, than of mechanical enquiry; but inasmuch as the operation of the steam engine cannot be understood without a previous acquaintance with theagent of its action, some few observations must be made on this subject which was first demonstrated to the world by Dr. Black, of Edinburgh, about the year 1757, and has since been corroborated by the labours and investigations of other eminent chemists. It has been stated that caloric, or the matter of heat, has the power of dilating or separating the particles of all bodies. From this it may be inferred that the solid state is that which is proper to all *simple* elementary matter, and that in proportion as it becomes compounded by mixture with caloric, it will become more or less fluid and elastic. Pure or simple matter is however unknown, for all known things are found to contain a certain quantity of caloric proper to themselves, called their specific heat, and which is perhaps necessary to their existence; but the quantity so contained is in many cases beyond the reach of experimental research, because it is not only latent and dormant, but imponderable and immeasurable by any of our instruments of investigation, which are only affected by free caloric, or that which is released, and made apparent to our senses by changes that may be wrought in the substance. Thus water at the temperature of 32 degrees Fahrenheit, will be in the solid state of ice, but still it is known to contain some caloric, because it may be cooled much lower, while on the contrary by adding more heat to it, it will forsake its former character of ice, and become fluid water, and so it will continue, (if in the open air,) until 212 degrees be added to it, when it changes into steam; and however much the fire may be urged under the water, still it will be found impossible to communicate a greater heat than 212 degrees to it, for all the additional heat will be conveyed away in the steam, instead of remaining in the water, unless indeed the steam be prevented from escaping by confinement in a close vessel when the heat may be augmented, as appears by the table at page 232.

This shows at once that a certain quantity of heat, and no more, can be contained in ice and water without changing their external characters, and in the same way, in reversing the operation it is found that before steam can be reconverted into water, or water into ice, as much heat must be taken away from it, as had been previously added to give it the character which it last assumed, and as the heat thus employed is free to combine with new matter, or to produce an equilibrium around its position, it shows that it is merely held in mechanical union or suspension, instead of entering into chemical combination. This at once explains the process of distillation, which is nothing more than boiling the fluid to be distilled in a close vessel, called *A Still*, while the steam is only permitted to escape through a long tube, bent into a spiral form to increase its length, and immersed in a tub of cold water, called *The Worm Tub*, in order that the steam may be cooled and recondensed in its passage. Cooling the steam however heats the water in the worm tub, which consequently requires to be frequently changed, or cooled by some process, otherwise it would loose its effect.

With permanently elastic fluids, such as airs and gasses, the case is quite different, for these are found to be composed of certain bases combined with caloric, (probably in a similar manner,) but united—*chemically* instead of *mechanically*.—The caloric so combined is consequently not at liberty to equalize or distribute itself, and therefore never becomes sensible or free, until the gas that before contained it is decomposed by entering into some new combination, when it may become sensible. But whether a gas is in contact with a hot or a cold body its own component quantity of caloric remains unchanged; and unless in the case of decomposition it will only part with that which is free or superabundant, and this it does without change in its own character, hence such bodies retain their ordinary characters and appearances, or are permanent under all variations of temperature.

From these circumstances the great importance and value of steam, as an agent for producing motion and power, are derived, for if a small quantity of water can by means of heat be made to occupy a very large space, and by cooling can be instantly reduced back again to its original dimensions, it is evident that a source of motion will be generated; and such a one is actually applied to the construction of the steam engine. This is pleasingly illustrated by an ingenious little toy, contrived by Dr. Wollaston, to show the nature of the above action, and which is, in fact, an epitome of the steam engine—its form is given at Fig. 113. It consists of a few inches of thin cylindrical or parallel glass tube *m n*, the top of which is open, while the lower end is blown into the form of a bulb as at *o* to contain a little spirits of wine. A piston seen near *n* is made to fit lightly into the cylindrical part of the tube, by wrapping a small quantity of tow or cotton wool round it, which will make it sufficiently air-tight for the purpose. The piston rod *p* is formed of a piece of very small tube or hollow wire, opening into the lower cavity of the tube *o*, so that by unscrewing the top ring *p* any air that is contained between *n* and *o* will escape on depressing the piston, after which its tube must be stopped by replacing its top *p*: *q q* is a spring ring and handle for holding the apparatus when in a hot state. Being prepared as above, if the bulb *o* be held over the flame of a candle or spirit lamp, the spirits of wine will soon produce steam, which by its expansive force will raise the piston from *n* to *m*, and would even project it altogether out of the tube, if the application of heat were continued long enough; but instead of permitting this to occur, the apparatus must be moved away from the lamp by its handle *q q*, and upon dipping the bulb *o* into a cup of cold quicksilver, the steam before produced will be instantly condensed and reconverted into spirits of wine, and a vacuum being thus produced in the tube, the piston will descend from the atmospheric pressure that will be exerted upon its upper part. A new application to the flame will produce a fresh elevation of the piston, while a fresh cooling will effect its depression, and thus the piston may be kept in a state of alternating motion during pleasure. After these preliminary observations the nature of the Steam Engine cannot fail to be clearly understood, and as it is altogether a truly philosophical machine, and one of the highest importance to mankind, it may not be uninteresting to take a brief view of its history from the period of its invention, and without entering into minute details, to trace it to its present state of perfection.

The first idea of obtaining primitive motion and power by the immediate employment of steam is, by almost general consent, given to the Marquis of Worcester, a nobleman of great knowledge and ingenuity who lived in the reign of Charles II., and who in 1663, first announced this invention in a small book which he published, under the title of "The Scantlings of One Hundred Inventions," and in which it stands as the 68th of his contrivances.

This book, usually called the Century of Inventions, contained nothing more than the mere names, and a very obscure account of one hundred inventions, which the Marquis in his prefatory address states that he had made; but he does not inform his readers how any one of them are to be carried into effect and several of the contrivances appear so extravagant, and so far beyond the reach of human power, that many have doubted whether they were ever invented or not, though this doubt is in a great measure removed by several of them having been since brought into existence. Thus the method of holding distant converse by the Telegraph is distinctly noticed, and the Steam Engine is described in such terms as cannot fail to identify the machine.—His words are, "I have invented an admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be as the philosopher calleth it, *intra sphæram activitatis*, which is, but at such a distance. But this way hath no bounder, if the vessel be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken end as also the touch-hole, and making a constant fire under it, within 24 hours it burst, and made a great crack, so that having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream 40 feet high. One vessel of water rarified by fire, driveth up forty of cold water; and a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refil with cold water, and so successively. The fire being tended and kept constant, which the selfsame person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

Such is the description that the Marquis gives of this invention, which is couched in such terms as not to be mistaken; and from his expressions it appears that he actually tried the effect of his machine on a considerable scale, though no traces are to be found on record of the machine he erected. It cannot but be matter of surprize that a machine stated to possess such astonishing powers should not have excited the public attention; but when it is recollected that the whole hundred inventions were published at once, and that many of them were of such an extraordinary description as to stagger belief, and that the work appeared in that age of em-

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, and the cock *z* be opened after the steam in the boiler is sufficiently accumulated, that steam will instantly rush down into the vessel *t*, and expel the whole of its water up the pipe *a x*, into the cistern *y*, where it will be retained by a valve opening upwards in any part of that pipe as at *a*. This done, the cock *z* must be shut, and after permitting the steam to accumulate for a short time that at *b* must be opened, when the steam will rush into the vessel *v* and perform a similar office, *c* being the valve to prevent the return

page 222 to 244

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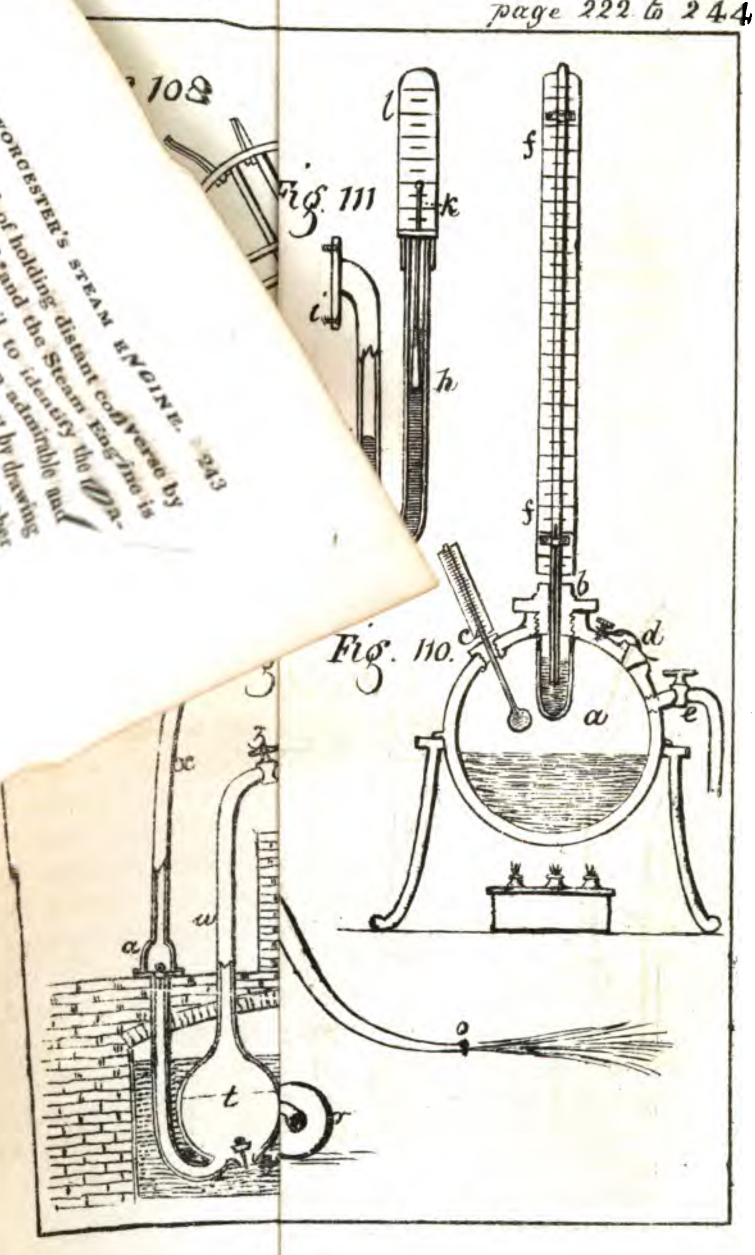

of the water. Now since the steam is shut off from the vessel *t* while *v* is emptying, it will be evident from what has been before observed, (page 238) that the steam sent into *t* to expel its water will become condensed by the cold water around the vessel *t*, and thus that a vacuum will be produced in that vessel, consequently a part of the water in which it is immersed will rush into it by the valve *u* and will fill it, and put it in a state of preparation for a second opening of the cock *z*, by which its contents will be again discharged into the cistern *y*, and so of the two vessels alternately, for while *v* is emptying *t* will be filling, and vice versâ, which agrees with the Marquis's account when he says, "that the man is but to turn two cocks, that one vessel of water being consumed another begins to force," &c. It must be understood however that the above Figure does not pretend to offer a representation of what the Marquis actually did, for of this, as before observed, we have no authentic record or representation. It is merely therefore the general arrangement of such a machine as the Marquis's description would warrant and suggest with our present knowledge of the nature of steam, and when it is considered that he only speaks of raising the water 40 feet in height, the power is not so great as might be at first expected, since raising it 33 feet is only equal to two atmospheres, and 40 feet is considerably short of two atmospheres and a quarter, or not quite 33½ lbs. of pressure on each inch of the boiler, if it were surrounded by a vacuum which is only equal to about 18 lbs. 10 oz. of actual pressure if it were in the open air; while high pressure boilers at the present day are frequently worked to 40 lbs. and upwards on the square inch, as will afterwards appear.

How the Marquis became acquainted with the astonishing power that he ascribes to steam, and whether he had ever seen or heard of its application to the purpose of raising water does not at all appear; but it is certain, notwithstanding the invention of an engine for using steam may belong to him, that attempts to use it as a motive power had been made before his publication, though probably without his knowledge; for the attempt of Brancas mentioned in p. 237, was made in 1628 or 9, when his machine was applied to work a stamping mill: and from a manuscript of Sir Samuel Morlands,* bearing date in 1683, it is evident that he also must have made many important experiments on the power of steam since he gives tables of the diameter and lengths of cylinders, which will raise given quantities of water taken in pounds weight to the height of 6 inches, 1800 times in an hour, a mode of calculation which it will afterwards appear approaches very nearly to the present improved method of estimating the power of engines.

Notwithstanding the Marquis of Worcester had thus clearly defined the nature of his invention, and Sir Samuel Morland had experimented upon it, and proved its efficacy, it does not appear that it was at all carried into effective execution until the year 1698, when Captain Savery obtained a patent for this engine as his own invention, stating at the same time that it would be of great public utility for draining mines, serving towns with water, and working all sorts of mills. The machine was then, and for a very considerable time afterwards, called the Fire Engine, from its motions being in the first instance produced by the agency of fire, but this name is now appropriated solely to those machines mentioned at page 206, which are used for the purpose of extinguishing fires.

The principles of Savery's engine are so nearly allied to those of the Marquis of Worcester, as to render a separate description almost unnecessary; yet however there is some difference, or at least it may be supposed there is in the construction. The Marquis of Worcester, it will have been observed, speaks only of the expansive force of steam without alluding to its condensibility, although this has been taken into account in explaining Fig. 114. Still however the condensation of the steam affords no other assistance to that machine than by filling the vessels *t* and *v* with water, consequently the whole effort of raising that water into the cistern *y* must depend alone upon the expansive force of the steam employed: Again from the vessels *t* and *v* being constantly under water, they will be kept in a very cold state, and all the first portion of steam that enters them must be condensed and lost, instead of being permitted to exert its expansive force, and as a very considerable quantity of steam must be dissipated in this way, so also the fuel employed to produce that steam must be wasted.

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* No. 5771 of the Harleian MSS. in the British Museum.

In *Savery's Engine* these inconveniences are to a certain extent removed, for instead of throwing the whole burthen of raising the water upon the force of the steam, he raises it as far as atmospheric pressure will permit, by a vacuum produced from the condensation of steam, and then effects the remainder of the lift by its expansive force; for instead of placing the water vessels under the surface of the water, they are elevated, and surrounded by air as will be seen at Fig. 115, Plate XI. which represents the general principles of construction of Savery's Engine. In this figure *d* is the steam boiler set in brickwork over a fire-place as before described, and *e e* is the pipe for conveying the steam; *f* is a cock by which that pipe is opened or shut at pleasure, so as to confine the steam in the boiler *d*, or permit it to pass over into the air-tight vessel *g*, which is firmly supported in its proper place. The lower part of this vessel has a suction or feeding pipe *h h* passing down into the well or reservoir from which the water is to be raised, and this pipe with its vessel *g* must be so placed that the upper part of *g* may not exceed the height of 30 feet from the surface of the water to be raised. A valve opening upwards is placed at *i* to prevent any water that may enter the vessel *g* from running down again through the pipe *h h*; an ascending pipe *k k* passes from the lower part of the vessel *g* to the cistern or elevated position into which the water is to be raised, and in some part of this pipe, as at *l*, a valve must be introduced to open upwards so as to prevent the descent of any water that may be thrown into this pipe. If we conceive such an apparatus to be constructed, and that the vessel *g* together with the pipes *h h* and *k k* are empty, it will be evident that on opening the cock *f* any steam that may have been generated in the boiler *d* will pass over into the vessel *g*, and being unable to escape through the valve *i*, it will pass upwards through the pipe *k k* and valve *l*, and will thus entirely fill the vessel *g* with steam, since the air at first contained in it will mix with the first steam, and pass away up the pipe *k k*. This done if the cock *f* be shut, the steam in *d* will accumulate and gain force by confinement, while *g* will remain filled with steam, and from what has been before observed, (page 238,) if *g* be cooled by throwing cold water upon it, or in any other way, its contained steam will be condensed or reconverted into water by which its bulk will be so enormously decreased as to occasion a vacuum in it, in consequence of which the pressure of the atmosphere will drive such a quantity of water up the pipe *h h* as to fill the vessel *g*, up to the dotted line *m m*. In the mean time the steam in *d* will have so far accumulated, that so soon as the cock *f* is opened a second time, it will rush into the vessel *g*, previously supplied with water, and by the exertion of its elastic force will drive the whole of that water up the pipe *k k* and once more fill the vessel with steam, which must in like manner be condensed immediately after shutting the cock *f*; and by a succession of these operations may any quantity of water be delivered up the pipe *k*, provided the steam in the boiler *d* is powerful enough to overcome the resistance of the column of water contained in *k k*, which may be ascertained by experiment, or reference in the table at page 232, for if the height of the pipe *k k* is 33 feet, or equal to the power of one atmosphere, from the explanation given at page 665, the steam must be equal to two atmospheres to raise it, and consequently it will require steam of the temperature of 245 degrees.

Such was the first state of Captain Savery's Engine, but he afterwards introduced many important improvements into it, which suggested themselves in the progress of the invention, for he erected many of these machines on a large scale. In the first place, it was found very inconvenient to throw water upon the vessel *g* to cool it, and as the ascending pipe *k k* must always be full of water after the first stroke, he introduced a pipe and cock into it as at *n*, by the opening of which a quantity of water was immediately discharged upon the outside of the vessel *g*. This was however attended with so great a waste of water, that he afterwards introduced the other end of the pipe into the inside of the vessel, as shewn in the figure, by which a much less quantity of water, produced a more rapid and perfect condensation. He likewise used two vessels like *g*, communicating by separate pipes to the same boiler, and thus while one vessel was discharging its water, the other was forming a vacuum and drawing up its charge from below; and by the adoption of a second or subsidiary boiler, he ingeniously contrived to compensate for that waste or reduction in the quantity of water which occurred from evaporation in the main or principal boiler, without having occasion to stop the machine to replenish it with water. This was effected by placing a small boiler by the side of the larger one, in such manner that both were heated by the same fire. Both the boilers were close, or shut up from communication with the external air, and a pipe with a cock passed from very near the bottom of the smaller boiler to the upper part of the larger one, consequently the steam that was produced in the small boiler pressed upon the surface of its own water, and as soon as the cock in the pipe was opened, all that water would be expelled in a boiling state from the small into the larger boiler, when the cock was again shut, and the small boiler replenished through a cock and funnel with cold water which remained in it, until it was in a boiling state; and thus the heat of the water in the large boiler was never checked by the introduction of cold water, a circumstance that is scrupulously attended to in the construction of the improved engines of the present day.

Captain Savery likewise invented and first applied what are called *Trial* or *Gauge Cocks,* for the purpose of ascertaining when the boiler contained its proper quantity of water, and these are likewise retained in all modern engines, and are of no small importance; for since an engine boiler from its nature must be close and opake, every thing that indicates with certainty, what is passing within it, becomes valuable.

The sitnation of the gauge cocks is shewn at *o p* and *q r*, in Fig. 115, and they are constantly placed in the upper part of the outside of the boiler, while the pipes *p* and *r* proceeding from them pass down into it. Before explaining their use, it may be necessary to state that all steam boilers, and particularly those for steam engines should be so capacious that the quantity of water to be boiled should not near fill them, but that a large space must be left above the water, to act as a reservoir or receptacle for the steam to rise into, as it is generated. If this were not done, the cylinder or other vessel to be filled with steam might contain more than the volume or space that existed above the water, and in that case it could not be supplied, at any rate with the necessary speed, while on the contrary, if the upper part of the boiler contains 5 or 6 times the volume of steam ready for action that the cylinder can contain, the quantity of one cylinder full can be taken away without very materially altering the density of that which remains behind, and the speed of the machine will consequently be maintained, while on the contrary, if this were not the case, it must be suspended until the continued action of the fire produced the necessary quantity of steam. It is therefore important that the water in a boiler should never rise much beyond some settled height, and it is equally necessary that the boiler should contain a sufficient quantity of water to enable it to produce steam, and to protect it from the action of the fire; for whenever a part of the metal that is exposed to the action of a violent fire ceases to be covered with water, it is in great danger of what is technically called, being *burnt*, i. e. it becomes red hot, decomposes and soon wears into a hole; an accident to which all engine boilers are liable, particularly when attended to by unskilful persons.

The gauge cocks when properly attended to, will at all times indicate the height of the water within a boiler while a fire is underneath it, with sufficient accuracy to prevent these accidents. They consist of two small brass cocks, screwed into the top of the boiler in an air-tight manner, and are united to pipes which pass down into the boiler; the pipe of the one cock being shorter than that of the other, by from 4 to 6 inches, while the entire length of the pipes is fixed by the water line of the boiler which is previously determined. Thus, if *s s* be the water line or height at which the water should stand in the boiler *d* Fig. 115, the pipe *p* of the cock *o* should proceed down into that boiler to within about 2 or 3 inches of that line; and the pipe *r* of the cock *q* should proceed to about 2 or 3 inches below that line, or dip so much into the water; consequently whenever the cock *q* is opened, boiling water should issue from it, but no steam, and on the contrary, whenever the cock *o* is opened, steam only should issue from it, and no water. This will be the case whenever the boiler is filled to its proper height, and will prove that the surface of the water is somewhere between the bottoms of the two pipes: should the boiler be too full of water, then its surface will be above the bottom of *p*, and water will issue from both the cocks, while on the contrary, whenever it is too low or below the bottom of *r*, steam will issue from both of them, but while steam issues from one, and water from the other, the boiler may be considered as containing its proper charge, and it may be worked with safety and advantage. When too great a quantity of water is contained in the boiler, a part of it must be drawn off, and on the contrary, when it does not contain enough, more must be added, which is provided for by a very ingenious contrivance to be hereafter described.

Captain Savery soon after the introduction of his invention published on account of its merits in a book entitled the *Miner's Friend*, in which he describes the invention as *his own*, and dwells on the importance of its applications to many purposes, among which it is not a little singular that the one of propelling or rowing boats or vessels by paddle-wheels as now practised in our steam boats is particularly noticed. The steam boat therefore which is generally considered as one of the most recent applications of the force of steam to useful purposes, it will be seen is by no means a modern invention, but is nearly coeval with that of the engine itself.

Savery's engine appears to have been used to some extent, and was the only construction adopted in England for several years, notwithstanding that it was a very expensive and wasteful machine to work, and one attended by considerable risk and danger, for the safety valve was not yet invented, and to raise water but 140 feet (which is a very insignificant depth for a mine) would require steam of the strength of nearly 60lbs. on every square inch of the boiler's surface. The expence of this engine arises from the facility with which steam is condensed by contact with a cold body, consequently all the first portion of steam that is thrown into the vessel *g* must be condensed by contact with the cold water that is contained in it, nor will it be capable of exerting its elastic force to any extent, until that vessel is rendered as hot as the steam itself, and when it has performed its office, the condensation that ensues requires that the vessel should be again cooled. It follows therefore that much more steam than is capable of filling the vessel *g* must be taken out of the boiler at each stroke since the first portion produces no other effect than that of heating the vessel to permit the second portion to act, and as a certain quantity of coals must be consumed to produce a certain quantity of steam, so those coals used to produce the first portion of steam are completely thrown away as to the production of power, and since the cost of fuel constitutes the chief expence of every steam engine it is evident that this cannot be a beneficial application, for reasons that will be more apparent when the more recent constructions of engines have been described.

Many consider Captain Savery as the inventor of the steam engine, not so much from his having appropriated the invention to himself in his book, as from his having been the first to carry it into actual execution on a large scale; and when the Marquis's loose and vague description is recollected, and that he does not descend at all into the minutiæ of executive construction, there appears to be no strong reason for depriving the Captain of the title of an inventor. Dr. Desaguliers however contends that there is no proof that the Marquis did not intend to use the contractile power of steam, and will not allow any merit to Savery, who he accuses of having taken the invention entirely from the Marquis's description, and even goes the length of asserting his belief, that he bought up and burnt every copy of the Marquis's book that he could meet with, in order to secure the invention to himself. This latter charge was however never substantiated by any other evidence, than that the book on a sudden became very scarce, and but few copies of it were afterwards seen, and those only in the libraries of the curious.*

It is not to be wondered at, that the invention of a machine promising such advantages as were expected from the steam engine, even in its infancy, should have been claimed by many, and accordingly notwithstanding its period is so well identified, yet some of the French writers claim it for their own nation, and give it to Amotons or Papin. It is true these ingenious men did construct engines to operate by the agency of fire, but the invention of the first, which is fully described under the name of *A Fire Mill*, in the memoires of the Royal Academy of Sciences of Paris for 1699, will be found to bear no resemblance in any part to a steam engine, while that of the latter is a most palpable copy of Savery's engine with such slight variations as not to entitle it to the name of a new invention. It must however be confessed that we are under some obligations to Dr. Papin for his improvements and discoveries in the application of steam, for that important appendage to every close steam boiler, called the *Safety Valve*, originated with him, and he discovered that water heated under the pressure of its own confined steam admitted a higher temperature than 212 degrees, and was capable of dissolving the *gelatine* of bones; hence such a close boiler with a loaded safety valve has been called a *Papin's Digester.* It was not however until after Savery had obtained his patent that the attention of Papin was at all directed to the means of obtaining a moving power by steam, for all his former investigations had been confined to the nature and temperature of steam when prevented from escaping. All his first attempts to obtain a moving power proved abortive, although carried on at considerable expence under the auspices of Charles, Landgrave of Hesse, and it was not until nine years after the date of Savery's Patent that he was enabled to produce a moving engine on principles very similar to Savery's, of which he afterwards confessed he had seen drawings.

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* The entire work has since been reprinted verbatim in the Second Series of the Repertory of Arts, Vol. I. page 180. For original see Harleian MSS. Brit. Mus. No. 2428.

A figure and description of what is denominated Papin's Steam Engine will be found in the Second Part of the Second Volume of *Belidor's Architecture Hydraulique;* but it is so very similar to Savery's Engine, already shewn at Fig. 115, as to render a separate representation of it unnecessary, for the boiler *d* is the same, except that instead of the guage cocks *o* and *q* a safety valve is substituted, *e e* is the steam pipe, and *f* the cock for shutting off the steam or admitting it into the vessel *g*, which in Papin's Engine is cylindrical from one end to the other, and has a flat top and bottom, so as to admit of a circular piece of wood (nearly fitting the bore of the vessel) floating upon the surface of the water as it rises and falls, and thus preventing the hot steam from coming into contact with the surface of the cold water, which, as far as it goes, is an improvement upon Savery; but as the water descends, it does not prevent the condensation produced by the wet and cold sides of the receiver, and therefore is of small importance. Instead of using the suction pipe *h h*, Papin supplies the vessel *g* with water by placing it so low, that it runs up into it as far as the line *m m* by its own effort, and thus the necessity of a nearly perfect vacuum in *g* is obviated, and consequently that of cooling this vessel to the extent already noticed.

From the simplicity of the construction of engines on Captain Savery's plan, many attempts have been made to improve and bring them into use; but the quantity of fuel necessary to produce steam of high temperature, and the greatest part of this being wasted at every stroke, they have generally failed to give satisfaction, although for small lifts when the quantity of coal is not an object, this engine is as good a one as can be resorted to for raising considerable quantities of water. A good example of the effective work of these engines may be taken from one, on rather a large scale, at the manufactory of Mr. P. Keir, at Camden Town, which when in good order delivers 7 cubic feet of water in a minute, at the height of 20 feet above the reservoir, making 10 strokes in a minute and consuming 6 bushels of coals in 12 hours' work. This water is employed to turn an overshot water wheel of 18 feet diameter, which by its revolution opens and shuts the cocks at their proper intervals, and turns lathes and other machinery in the manufactory. This is about half the power that would be obtained from the same quantity of coals if burnt in producing steam for an engine of the latest and best construction.

Among the attempts that have been made to improve this kind of engine, those of Mr. William Blakey, of Mr. James Boaz, of Glasgow, and Mr. J. Pontifex, of London, are the best; the two latter gentlemen obtained patents, and the former was tried many years ago in a mine in Cornwall with sanguine hopes of success, but an accident terminated the experiment; for the steam vessel burst with such a terrific explosion as prevented the adventurers from making any further prosecution of the scheme, which consisted in the employment of two steam vessels, like *g* Fig. 115, but the one was placed over the other with an open pipe of communication between them. The steam was only let into the upper vessel while the lower one was filled with air, which being acted upon by the alternate dilations and contractions of the steam was to transfer that action again to the water, the surface of which was covered with oil, the more effectually to prevent the transmission of heat. This contrivance was altogether too nice and delicate to admit of practical application, but as the condensation was to take place in the lower vessel while the air and steam were mixed together, and the upper vessel was not to be cooled at all, it was expected that the steam would condense into water, while the air would merely suffer a little diminution of volume, and occupy the upper vessel ready to receive a second charge of steam, while the lower vessel would be filled with water, and so on alternately, but the result proved unfavourable.

It may be worthy of remark that the boiler used on this occasion was not a large close vessel set over a fire, but consisted of a series of iron pipes connected together, and laid in sloping directions within the furnace; a mode of construction which will be found to coincide very nearly with what is usually considered a modern improvement, and which will be hereafter described in conjunction with what is called Woolf's Steam Engine.

The experiments that were made with Savery's and Blakey's Engines in the Cornish Tin mines led to the next grand step that was made in the improvement of this important machine: for a Mr. Newcomen, of Dartmouth in Devonshire, had frequent occasion to visit these mines, and being a man of keen penetration and considerable science he saw the dangers and difficulties to which they were exposed, and was enabled to contrive a machine by which they were in a great measure obviated, though some contend that the merit of this invention belongs to Papin. Papin it appears was about the same period engaged in some projects for producing a moving power, through the agency of atmospheric pressure, and transmitting it to great distances by pipes, though it is not evident that he had at all made up his mind as to the best means of producing the necessary vacuum, for at one time large air pumps to be worked by a powerful mill were proposed; at another the firing of gunpowder; and lastly, the production and condensation of steam. Although these schemes were published, it does not appear that any one took advantage of them or constructed an engine upon such principles, till the time of Newcomen, who is therefore considered as the inventor, although it is tolerably certain, that he was acquainted with Papin's ideas, as appeared by some correspondence and papers of Dr. Hooks, which were found after his death.

Newcomen's Engine was the first in which a truly bored cylinder with a well-fitted piston working in it was applied, and the aid of atmospheric pressure called in, instead of the less controulable power of steam, on which account this machine is very generally called, *The Atmospheric Steam Engine*. The great advantage that it possesses over Savery's engine is that the steam is in no case required to be much stronger than what will balance the pressure of the atmosphere, by which all danger is removed, and a much less consumption of fuel required. Mr. Newcomen obtained a patent for his machine, and associated himself with a Mr. Cawley, a glazier of the same town in its construction; but in the early stage of the discovery it appears that he, as well as Dr. Papin, had not made up his mind to the use of steam, but merely contemplated that if he could produce a vacuum under a piston in a large cylinder, the pressure of the atmosphere must bring it down with such force as to produce a useful disposable power; and had he not seen the effects of Savery's engines in Cornwall, and the vacuum they produced by steam, it is probable he would not have thought of resorting to this agent. He was even dissuaded from prosecuting his experiments by the celebrated Dr. Hooke, from a conviction that it would be impossible in practice to obtain such a vacuum under a large piston, as could be productive of beneficial effects, although he admitted that if this could be effected, the machine must answer. The method of obtaining a vacuum by condensing steam was however the property of Captain Savery, and had been secured to him by his Patent; consequently Newcomen could not use it until a negociation was made between the parties, and a New Patent was obtained in 1705, in which the names of Savery, Newcomen, and Cawley, appeared as partners, although it was known that the only assistance Savery rendered, was granting the permission to use his patent method of obtaining a vacuum.

The construction of Newcomen's engine, as it now appeared, is shewn at Fig. 116, in which *t t* is the boiler and fire-place as before described for producing steam, *v* is a cylinder, truly bored in the inside, having an open top and close bottom, by which it is connected to the top of the boiler by a short pipe *u* containing the steam cock. A piston *w* is made to move up and down in the cylinder in an air-tight manner with as little friction as possible, by packing its edge with loose hemp, and covering its upper surface with water. The piston rod *x* is attached by a chain *y* to the circular part *z* of the apparatus *z a b*, which is called the *Beam of the Engine*, which was now first introduced. The engine beam was formed of strong timbers firmly framed together, strengthened by iron bars and straps, and constructed so as to move and balance upon the iron gudgeon or axis *a* supported upon a strong brick wall *c*, being usually one side of the house for containing the engine, and so that the end *z* of the beam was within the building while the end *b* projected into the open air. Another chain *d* is attached to the external circular end *b* of the beam, and from this the piston rod *e e* of the pump to be worked in the well or mine *f* is suspended. This last piston rod is attached to any of the pumps shewn at Figs. 95, 96, or 100, which raise water by the ascent of their pistons, because the power of this engine is in the up stroke of the end *b* of the beam. When the depth of the well *f* is considerable, the piston rod *e e* will itself be sufficient to act as a counterpoise, but should this not be the case, then weights as at *g g* must be added to the rod until it rather over-balances the weight of the steam piston and rod *w*, *x* and its friction in the cylinder, so that when the cock *u* is opened and air is permitted to pass into the lower part of the cylinder *v*, the piston *w* may rise to its top without violence; but should the pump piston rod *e e* be so heavy as to draw the steam piston *w* up too violently, or to draw it up against the pressure of the atmosphere which will act upon it when the cock *u* is shut, then counterpoise weights must be added to the steam piston *x*, or the end *z* of the beam, until the machine is properly adjusted, which will not be the case, until the steam piston *w* rises equably and gradually upon opening the cock *u* to admit air; for during this adjustment it is presumed that no fire is under the boiler, and consequently that no steam is produced. A safety valve opening outwards is placed upon the upper part of the boiler as at *h*, and this is kept closed by the lever *i* and weight *k*, which by being placed nearer to, or further from the valve, will act with more or less power, and will permit the escape of the steam, should it at any time become too violent. Having so far described the form of this engine, its mode of operation will be found very simple. Thus to set it to work the boiler *t* must contain its proper quantity of water, and the cock *u* being opened the steam piston *w* is to be drawn downwards until it touches the bottom of the cylinder, by which all the air previously contained in it will pass downwards through the cock *u* into the boiler, and from thence will escape by the safety valve *h*. The cock *u* is now to be shut, consequently the piston *w* will be prevented from rising by the pressure of the external air upon it. In this state the machine stands, until by lighting the fire, steam is produced of rather more power than is equivalent to the pressure of the atmosphere, when upon opening the cock *u*, in a greater or less degree, that steam will enter the cylinder *v*, and permit the piston to ascend, partly by the force of the steam, but chiefly in obedience to the counterpoise weights *g g*, so that the velocity of motion may be regulated to the greatest nicety. Just before the piston reaches the top of the cylinder, the steam cock *u* must be shut, by which the beam will become stationary, and the cylinder will remain full of steam until it is condensed by cold. In order to effect this condensation a small cistern *l* is fixed in an elevated position, and is supplied with cold water by a pipe *m m*, proceeding from the pump in the well *f*, and *n* is another pipe proceeding from the bottom of the cistern *l* into the bottom of the cylinder *v*, so that by opening the cock at *o* a small quantity of water is let into the cylinder to condense the steam and produce a vacuum, when the pressure of the external air will act on the top of the piston *w*, and cause it to descend with a force proportionate to its area; and as this pressure will amount to very nearly 15lbs. upon every superficial inch, it will be fully competent to raising the end *b* of the beam, and any pumps or other load that may be attached to it; for if the cylinder is but 2 feet in diameter (which is by no means large for such an engine) the area of its piston will contain 452 inches and three quarters, which multiplied by 15lbs: or the pressure upon a single square inch amounts to no less than 6785¾lbs. and deducting 1-fourth for the friction of the machine, the effective force remaining to operate on the piston will be 5089½lbs.

This engine was at first much less perfect than above described, and had many defects and inconveniences which were gradually removed; for the condensation was in the first instance performed on the outside of the cylinder instead of admitting the water within it, and the greatest nicety and attention on the part of the workman was necessary in turning the two cocks at the precise necessary periods; for if the steam was permitted to enter the cylinder for too great a length of time, the piston would be carried above it, and would be blown out of its place; while on the contrary, if the cock was not opened soon enough when the piston was descending, it would strike against the bottom of the cylinder with such force as to break it to pieces. The steam by which the engine is worked is also constantly mixed with a certain portion of air which is disengaged from the water in boiling, and this together with the cold water injected into the cylinder for producing condensation was found to accumulate so fast that a pipe became necessary to lead into a cistern below, for their discharge. Such a pipe was accordingly adopted and was made to terminate in a valve at its lower end, to preserve the vacuum, and this valve from the peculiar noise it was found to make, was called the Snifting Clack. The situation of this pipe and valve are shewn at *p p* in the figure. The water, and any air the cylinder might contain were thrown out at this valve by the last effort of the piston in descending before it struck the bottom, and thus the cylinder was cleared between each fresh introduction of steam. Considering the difficulties attendant upon the perfection of so complicated a machine as the steam engine, it is truly astonishing to observe the rapid strides towards perfection which it made within 7 years after its first introduction in 1705. Some of its improvements it is true were accidental, for that of condensing by the injection of cold water into the cylinder instead of applying it externally arose from some holes being in the piston of an engine, which permitted the water placed upon it to keep it air-tight to run through and condense the steam: and the great difficulty of opening the cocks at the proper moment was conquered by a boy named Humphrey Potter, who attached some strings and catches to the cocks of an engine he was employed to work at Wolverhampton, in order to release himself from the trouble of attending to them, and which, although clumsily contrived, performed their office very well and gave the first idea of that machinery called *Hand Geer*, by which the valves or cocks of all steam engines are now worked, by the immediate action of the engine itself.

This description of Engine could not be said to be in a perfect state before the year 1718, when Mr. Henry Beighton, of Newcastle upon Tyne, erected a powerful steam engine on this principle, with many important improvements, relating however chiefly to the working parts, and the manner of admitting and shutting off the steam, by means of what he called a Plug Tree, which acted upon certain levers and catches for working the valves: the fixing of the cylinder was likewise much improved by him, but still it was placed immediately over the boiler as at Fig. 116. He likewise first applied a small forcing pump to throw water into the boiler, in order to supply the waste of evaporation, and the machine, though not altered in principle, was considered so perfect with his additions that further improvements were scarcely expected in it, and it remained unchanged, though almost universally adopted, for nearly half a century under the name of Beighton's Fire Engine.

After the account that has been given of the enormous force that is brought into action in the cylinder of one of these engines when at work, the impropriety of fixing such a cylinder upon a boiler, supported over a strong fire, must be apparent; for however strong the brickwork of the fireplace may be built, still it must be subject to rapid decay from the action of the fire, and whenever this occurs, a derangement of the adjustment of the whole machine must follow; and notwithstanding the improvement of Mr. Beighton, who supported his cylinders between strong timbers, so as not to let them depend altogether upon the brickwork of the boiler, still there was so much vibration that the furnace was soon shaken and destroyed; for the piston in its up stroke would actually lift up the entire boiler and cylinder as much as the springing of the timbers would allow, and would depress and replace them at the return of the stroke; an effect that all who can recollect the action of these engines must have seen, and which the author has often noticed in one of the most perfect engines of this construction that could be erected in the time of the ingenious Mr. Smeaton, being that at the late York Buildings Water Works, in Villiers-street, Strand, and which was pulled down in 1813, to make room for one of the more perfect machines of Messrs. Watt and Boulton. The above-mentioned defect was however removed in some cases, by resorting to the former construction of Captain Savery, that is to say, placing the cylinder beside the boiler, instead of above it, and bolting it down to a solid and massive block of brickwork and masonry, having no connection with the fire. By this means, not only more stability was insured, but the former great height, and consequent expence of the engine-house was dispensed with.

The steam engine being at this time considered as perfect, the attention of men of science was not so much directed to its mechanical improvement, as to the means of preventing its consumption of fuel; for the engine at this period was never used but on a large scale, and whenever it was introduced it was found to be a most extravagant devourer of this article. The nature of heat and steam were not however yet sufficiently understood to show that the radical error was in the engine itself, and not in the boiler which was afterwards discovered, and accordingly about this period we find many experiments tried on different forms of boilers to produce the greatest quantity of steam with the least fuel. Among these may be named Mr. Payne's expedient described in No. 461 of the Philosophical Transactions, from which great effects were expected, but which in practice did not answer any good purpose. It consisted in supplying very minute streams of water by a revolving set of jet pipes, to the inside of a hollow inverted cone of cast iron which was kept in a red hot state by a surrounding fire; but the water was decomposed rather than converted into steam, therefore very little was produced, and it was abandoned. It was however very soon ascertained that the form of boiler which exposed the greatest quantity of surface to the action of the fire and did not permit its heat to pass up the chimney until nearly the whole of its power had been exhausted, was the best, and accordingly in some of the boilers constructed under the direction of Mr. Smeaton, the flame and smoke had to pass through a complete labyrinth of channels; but the number of angles and sharp corners that were thus exposed to the action of the fire were not only very liable to be burnt or destroyed, but made the construction of the boiler much more expensive, without producing a proportionably beneficial result, in consequence of which the form of engine boilers is now much simplified, and even in those of the largest engines, Messrs. Watt and Boulton employ but one central flue or chimney through the boiler, which has generally the form shewn at Fig. 117, and which from its resemblance to the body of a waggon with a tilt thrown over it, has very generally obtained the name of the waggon boiler. It is made of an oblong shape like *a b c d* with a semi-cylindrical covering *e f*, which is the only part that projects and is visible above the brick-work of its setting. The size of these boilers varies from 5 feet to above 20 feet in length, according to the power of the engine to which they are applied, while their width and depth is made according to certain established proportions. Thus for what is called a 20-horse power steam engine the boiler is usually 15 feet long by 6 feet wide, so as to have 90 superficial feet on the surface of the water, while the height from the bottom to the top of the dome is 7 feet. A boiler for a 14 horse engine, in like manner exposes about 60 feet of surface; and one of 80 horse power would expose 360 feet, and so on. The fire is made on the bars *g*, extending about half the length of the boiler or rather less, while *h* is the ash hole for the cinders to fall into; the brick-work of the fire-place rises above the bars at *i i* so as to form what is called the bridge, to stop the fuel from entering the flues and to throw the flame more immediately against the bottom of the boiler, after which it is conducted by the arched flue *k* into the metal tube or flue *l m*, passing through the entire length of the boiler under the surface of the water to be boiled, and by this the flame and smoke is brought to the front *m*, from whence it is carried back again by two horizontal flues *n n*, running along the two sides of the boiler, and which conduct it into the rising chimney *o*. An oval cast iron plate *p* is usually fixed with screw bolts and nuts over a hole in the upper part of every boiler, being of sufficient size to permit a man to pass through it for cleaning, repairing, or examining its inside, on which account this orifice has obtained the name of the *Man Hole*: *q* is the mercurial steam gauge, (see page 235) *r r* the gauge cocks described at page 250, and *s* is a cock for emptying the boiler of its water, or drawing off any portion of it that may be superfluous: *t t t* is the brick-work of the furnace or fire-place, the front part of which is supposed to be taken away to show the boiler, bars, flues, &c.

All the engines that have been so far noticed (with the exception only of the scheme of Amontons) are either for the immediate purpose of raising water, or are only capable of producing a vertical reciprocating motion from the rising and falling of the piston, which may either be immediately brought into action, or may be communicated in a secondary manner by the beam as in Fig. 116, in which case the suspending chains *y d* working over the circular ends of the beams *z b* (and which from their motion and general appearance obtained the name of horse heads) would be quite sufficient, because the strain upon both the chains whether arising from atmospheric pressure on the steam piston at one end, or the column of water to be lifted by the pump at the other, would always be downwards and perpendicular, and the circular ends of the beam being concentric with its center or axis would also answer the purpose of making the piston rods at both ends work perpendicularly and parallel to each other. But when a more intimate acquaintance with the power of the steam engine induced mechanics to turn their attention towards using it as a prime mover for giving motion to machinery as well as for pumping water, it became necessary in many cases to convert the reciprocating action of the beam, into a constant rotatory motion, which was quite impossible with the chains and segments already described. Mr. Keane Fitzgerald appears to have been the first person who attempted this valuable improvement:—He did it, as appears by the Philosophical Transactions for 1759, by discarding the above-mentioned chains, and forming teeth or cogs on the outer edges of the end segments of the beam, which teeth acted into wheels or pinions equipped with ratchets or palls. Although this contrivance was ingenious yet it was very difficult to make it effective, on account of the unequal motion and power of the piston, which in its highest and lowest positions is for a short time, without motion and consequently without power; and therefore although Mr. Fitzgerald obtained a patent for his invention, it neither appears to have been used, or brought to perfection, nor indeed was the steam engine rendered at all effective for producing rotatory motion until the crank and fly wheel were resorted to in the way that they are now constantly employed for this purpose. Fig. 118, shews the manner in which these appendages are applied to a steam engine; *v* being the end of the beam opposite to that on which the piston acts, and *u u* a heavy fly wheel of cast iron, which is not unfrequently from 10 to 20 feet in diameter, and weighs several tons. It turns upon a shaft or axis *x*, firmly supported by proper framing, and to that same axis the crank or arm *w* is affixed, its opposite end *z* being attached through the piece *y* called the connecting rod by a swivel joint to the end *v* of the beam. The crank must be so fixed to the fly wheel shaft, that when the beam is horizontal or in the middle of its stroke, the crank may be horizontal likewise, consequently when the piston is quite down the end *z* of the crank will be quite up, or above its axis *x*, and just below it when the piston is quite up. In these two positions the piston can have no power to urge the crank and fly wheel round, as it has in every other situation; but since the fly wheel will acquire momentum by moving, so the motion communicated to the crank while it passes from the upper dotted position *a* to the lower one *b* will generate so much momentum as to prevent the wheel from stopping when the crank arrives either at *a* or *b*, and will thus carry it over or under the center when the piston has no power, and consequently will place it in a favourable position to be acted upon, so soon as the piston resumes its motion and force. In this way the reciprocating motion of a steam engine beam can be converted into rotatory motion with the greatest regularly and precision, provided the fly-wheel be sufficiently large, heavy, and swift in its motion, to maintain the power at the expence of its own momentum during the momentary suspension of the power of the engine, or while the piston is changing its direction. The fly and crank not only produce rotatory motion in the steam engine but answer another very important end in limiting the length of the stroke of the piston with the greatest precision, and thus prevent the possibility of those accidents already alluded to, of the piston striking against the top or bottom of the steam cylinder. They were first applied to engines by Mr. Mathew Washbrough, of Bristol, who obtained a patent for the invention in 1778.

Of all the improvements which have been made in the steam engine those of Mr. James Watt, of Soho, near Birmingham, are the most perfect and surprising. It may be considered as a fortunate circumstance for the world, that his capacious and enlightened mind should have been directed towards this machine, which arose from his having a small working model of a steam engine belonging to the University of Glasgow to repair in the year 1763. Dr. Black was at the same time actively pursuing his important researches on heat, and investigating the cause of its becoming latent in boiling fluids, and Mr. Watt being intimately acquainted with him and the objects of his pursuit, was induced to try some experiments on the production and condensation of steam as a matter of amusement. In the course of these, many curious facts were developed, and among others the remarkable one, that when a quantity of water is heated in a close vessel to several degrees above the boiling point, if a cock or valve be opened, the steam will rush out with violence, and the heat of the water will in two or three seconds be reduced to the ordinary boiling point, notwithstanding the bulk of water may be very considerable. This sudden cooling he accounted for by supposing that the steam in escaping carried all the superabundant heat with it, which has since been found to be the case. He reasoned therefore that since steam contains, and is capable of bearing away so large a quantity of heat, it must require a great quantity of fuel to produce it in large quantities, which no form or construction of boiler or furnace can obviate. It was before known that water boiled in an open vessel, could never be heated to more than 212 degrees, however intense the fire, and Dr. Black discovered that all the superabundant heat, after producing 212 degrees in the water was carried away by the steam, so long as it was permitted to escape, but that when confined, the excess of heat discovered by Papin was the consequence. Mr. Watt, therefore, instead of considering the engine as perfect and attempting improvements in the boiler, as others had done before him, turned his attention towards economising the heat that was produced, and the method of using it to the greatest advantage.

He found that the cylinder of his little engine became so hot as not to admit of being touched by the hand the instant that steam was let into it; because the cylinder began to cool the steam, or abstract its heat, and would not permit it to exert the same elasticity as it had before it entered, until the cylinder was as hot as itself. He likewise conceived that all this quantity of heat must be thrown away, because, before the piston would descend with any considerable effect, the cylinder required to be again sufficiently cooled by the injection of cold water, to re-condense that steam and bring it all back into the state of water; after which it required to be heated again before it would make its next stroke; consequently, all that portion of heat which was expended to warm the cylinder between each stroke was not only thrown away, though produced at a great expence of fuel, but was actually detrimental to the working of the machine, because it was much more difficult to cool, than to heat the cylinder suddenly. Mr. Watt, therefore, instituted some experiments to ascertain the quantity of steam thus wasted in warming the cylinder between each stroke, and found it no less a quantity than three times the contents of the cylinder, so that each stroke of the engine, instead of taking one cylinder full of steam away from the boiler, actually took four. The three first measures being completely wasted without any other effect than heating the cylinder to such an extent as permitted the fourth measure to perform its office of moving the Piston. This necessary heating and cooling of the cylinder he was convinced was the radical imperfection of the engine, but how to remedy it was the difficulty, for his experiments shewed him that to use the steam with the best effect, the cylinder should always be kept as hot as the steam itself, and yet if this was done, no condensation could be effected. His first attempt at improvement was by substituting a wooden cylinder, for the metallic one before used, from an idea that as wood was a much worse conductor of heat than metal, it would not carry off the heat so rapidly. The wooden cylinder was attended with the effect expected, which fully confirmed Mr. Watt in the truth of his assumptions, but from its swelling and becoming rough when filled with steam, the friction became so increased as to forbid the use of this material, and he returned again to the brass cylinder, which he now cased on its exterior parts with wood, and filled up all the interstices with powdered charcoal so as to prevent its being cooled, as far as possible, by the external air. By this expedient, and injecting no more water into the cylinder than was absolutely necessary to condense the steam he succeeded in reducing the waste, to one half of what it had been before. But by using so small a quantity of condensing water, although the steam was saved, the power of the engine became very materially diminished; for the cylinder was never cooled much below the boiling point, consequently the condensation within it was very imperfect, and a quantity of steam possessing considerable elasticity still remained, and counteracted the pressure of the atmosphere in a very considerable degree. He was, however, quite convinced that the condensation taking place within the cylinder, must either be of this imperfect nature, or if rendered otherwise by additional cooling, that steam must be wasted; and hence had nearly concluded that the steam engine was incapable of further improvement, and was in as perfect a state as possible, when the happy thought occurred to him of condensing the steam in a separate vessel, instead of within the cylinder of the engine. This expedient was immediately tried in a very simple manner as follows; a globular copper vessel was made to communicate by means of a pipe containing a cock to shut it, with a hollow tin cylinder 30 inches long and 4 inches diameter. The globe was filled with steam by connection with a small boiler, while the tin cylinder was immersed in cold water, and upon opening the cock to form a communication between the two vessels, the sides of the tin cylinder were instantly crushed together on account of its not being sufficiently strong to withstand the external force of atmospheric pressure, so perfect was the vacuum that was formed within it. This experiment exceeded his most sanguine wishes, and upon it, he founded all the important improvements which he was afterwards enabled to make in this important machine. A new model was imme-

Fig. 116.

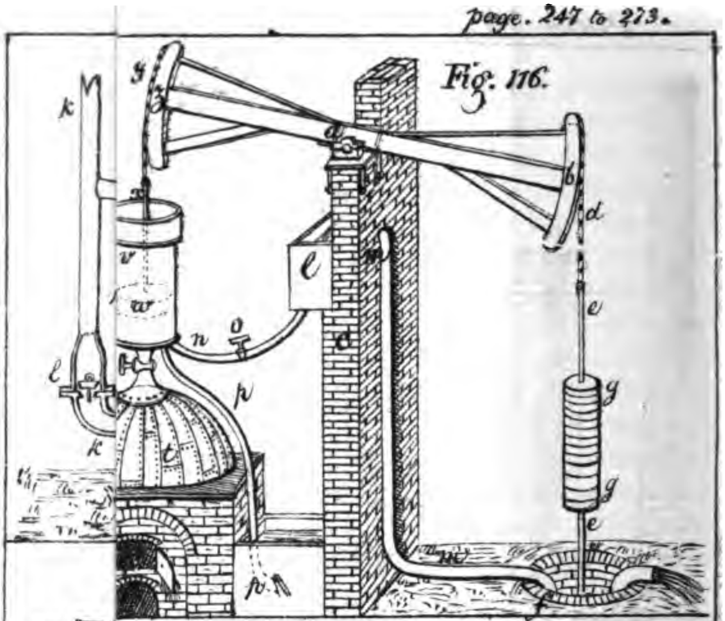

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Fig. 118.

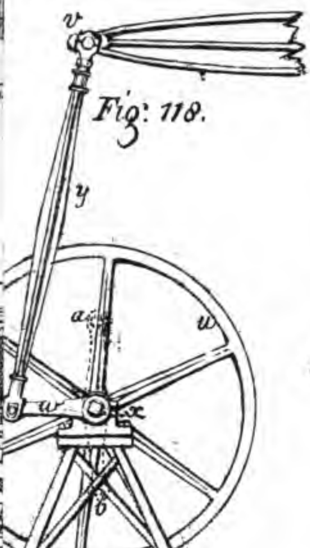
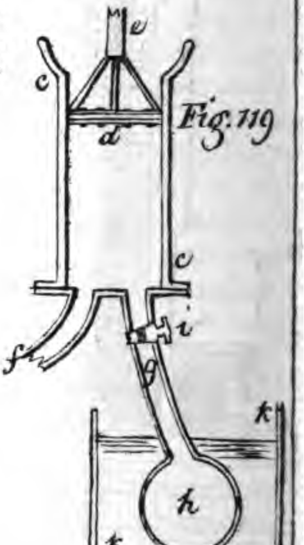


Fig. 119



diately made in which the parts were disposed, as shewn at Fig. 119, in which *c c* is a section of the cylinder of a steam engine as then used, *d* being the piston to move in it, and *e* part of the piston rod, *f* part of the steam pipe communicating with the boiler to supply steam, *g* a pipe leading from the bottom of the cylinder and terminating at its lower extremity in a hollow copper ball *h*, which, together with part of the pipe *g*, was immersed in a cistern of cold water *k k*, and *i* a cock for cutting off the communication between the cylinder *c c* and ball *h*. While the cylinder was receiving its steam the cock *i* was shut, and so soon as the piston *d* was raised, and the steam cut off by closing the pipe *f*, the cock *i* was opened, and a part of the steam entering the ball *h* was condensed so as to produce a partial vacuum, by which the remaining steam entered the ball, and the whole was condensed with astonishing rapidity and the most perfect vacuum produced without at all diminishing the temperature of the cylinder *c*, which was all that could be desired, for now the piston was driven completely to the bottom of the cylinder, instead of stopping at about one-eighth from it, as it had formerly done, and this without any waste of heat. This arrangement however plausible it may appear, was still attended with many practical difficulties in its execution, for all the steam that was condensed in the ball *h*, and to which the name of the condenser was applied would be converted into water within that ball, and would consequently soon fill it, so as to render it incapable of performing its office; besides which the water in the condenser cistern became warm, and unfit for the purpose of condensation. Mr. Watt therefore soon found the necessity, not only of drawing off any accumulation that might occur in the condenser, but likewise of renewing the water in which it was placed, so as to keep it as cold as possible. He likewise saw that if the contents of the condenser were removed from time to time, the air within it might at the same time be rarified, and thus that the steam would enter it more readily which was desirable; and accordingly he proposed several means for emptying the condenser, one of which was to carry an open pipe from its bottom to the distance of above 35 feet, and to immerse its lower end in a well or cistern of water, thus converting the condenser into a water barometer, by which its contents would be discharged, since we have already seen, (page 185,) that atmospheric pressure can never sustain a column of water of this height. But from the inconvenience of establishing so high a column, Mr. Watt preferred the use of an air, or exhausting pump, which he applied to the lower part of his condenser, and as this pump could be worked, by the motion of the beam of the engine, so it possessed within itself the power of emptying its own condenser, of all water, steam, air, or other fluid that might accumulate within it.

Mr. Watt's only apprehension in using a pump was, that it might load the machine with such a quantity of additional friction as might be detrimental to its action, but he was soon convinced that his suspicions were groundless, for the condensible power of steam, when properly treated, he found was much greater than he had even suspected, and he found that instead of making his condenser as large as the acting cylinder, that a small vessel, or even a pipe, was capable of condensing the steam of a large cylinder, consequently the condenser pump, or as it is now universally called the Air Pump of the Steam Engine does not require to be large and therefore takes away but little of the power of the machine.

The steam engine, as first proposed by Mr. Watt, therefore consisted of the boiler and steam cylinder in nearly the same form as used by Newcomen and Beighton, as before described, except that the cylinder was coated with wood to keep it hot, and in lieu of the snifting valve and eduction pipe, for the escape of the air and condensed water, and the injection pipe, to throw cold water into the cylinder, he used an air pump working into the condenser which was connected by a pipe to the lower part of the cylinder and placed in a cistern of cold water which was constantly replenished by a common pump drawing water from the nearest well or spring, and delivering it into the cistern in which the condenser was placed; while the surplus water escaped and ran to waste, by an outlet in the upper part of the cistern, because the heated water being lighter than the cold, and less fit for producing condensation, would naturally rise to the top. The water drawn from the condenser by the air pump was likewise carried away by a drain, because being in a warm state it was unfit to be used again for condensing, but a part of it was thrown back into the boiler by a small forcing pump, in order to supply the waste of evaporation. All these several pumps were worked by the beam of the engine, and instead of the cocks or sliders that had before been used, new and more perfect valves were adopted for admitting steam and shutting off the condenser at proper intervals, all of which were opened from the motion of the beam by the plug tree and hand geer introduced by Mr. Beighton.

The general arrangement of Mr. Watt's engine at this period as above described is shewn at Fig. 120, Plate XIII. but the disposition and manner of fixing the parts is not there attended to,— 1st. because in the real engine one part might come behind another and would therefore be invisible; and 2dly. the arrangement became materially altered as the engine was still further improved. Still all the parts included in this figure were retained with simple alterations, and the use of it is therefore to make the reader acquainted, not only with the names of these parts, but the offices they have to perform, so that in afterwards describing the actual form of the engine it will merely be necessary to call them by their names without further description, and in this figure, cocks are retained in the pipes, instead of the proper valves for the sake of simplicity. A is *the Steam Pipe* communicating from the boiler, in which steam is generated, to the lower part of *the Steam Cylinder* B, and *a* is the cock for admitting or shutting off the steam, therefore called *the Steam Cock* or *Valve.* C is *the Piston* moving in an air-tight manner upwards and downwards in the steam cylinder. D *the Piston Rod,* the upper end of which is connected to one end of the engine beam (as at x y z Fig. 116.) E a cock and pipe leading to an elevated cistern, by which a little water can be discharged on the top of the piston to keep it air-tight. F F section of the wooden *Casing* or *Jacket*, as it is technically called, that is applied round the exterior of the steam cylinder to retain the heat. It is made in separate staves, and fixed in its place by iron hoops like a barrel. G *the Eduction Pipe* leading from the bottom of the steam cylinder, to the upper part of H *the Condenser,* which is a hollow metal vessel of any convenient form placed below the steam cylinder in a large cistern of water I I, called *the Cold Water Cistern: b* a cock called *the Eduction Valve,* for opening and shutting off the connection between the steam cylinder and the condenser. K *the Air Pump* also fixed in the cold water cistern, but without any internal communication with the water it contains. This pump is of the common lift construction (page 195), except that its valves are of metal, on account of the heat of the water: its lower valve *c* is called *the Foot Valve.* L is its Piston Rod, the upper end of which is connected to, and works by the engine beam. M is its Suction Pipe communicating with the bottom of the condenser H, in order that it may draw off all the air and water it contains, and this water, being in a hot state is delivered into the smaller cistern N, therefore called *the Hot Water Cistern.* O is a common pump, called *the Cold Water Pump,* because it supplies cold water to the cistern I I, being worked by the beam, in the same manner as the air pump. The surplus cold water runs off into a drain by the spout P, and the hot water by another spout at Q. The other objects in this figure refer to more recent improvements upon the machine, and will therefore be afterwards noticed.

After what has been said upon the steam engine, but little explanation can be necessary of the operation of this machine, for if the piston C is at the bottom of the cylinder, and the steam valve *a* be opened, steam will rush into B, and permit the piston to ascend in obedience to the counterpoise weights at the opposite end of the beam, until it is sufficiently raised, and at the same time the piston of the air pump will rise and produce a partial rarefaction in the condenser. So soon as the piston has got to its proper elevation, the cock *a* must be shut, and *b* opened, when the steam in the cylinder will rush into the condenser and be condensed, thereby producing such a vacuum as will cause the steam piston to descend; when *b* must be shut and *a* opened to produce a second rising of the piston C, during which the air pump K will draw off any condensed water that was deposited in H, and deliver it into N, thus preparing the condenser for making a second vacuum, which it is enabled to do by the cold water pump O, keeping the cistern I I constantly replenished. To increase the power of condensation, Mr. Watt found it necessary to place a cock as at *g*, for admitting a small stream of water to run from the cistern into the interior of the condenser in such a direction as to meet the steam, by which the condensation was not only rendered more rapid but more perfect: this is called *the Injection Cock.*

In this state of the engine Mr. Watt found that it consumed but little more than half the fuel required by all the other constructions that had preceded it. But still he was not satisfied with the perfection of his machine; for the steam cylinder had an open top, and required water to lie upon the top of the piston to keep it air-tight, consequently whenever the piston descended, the whole interior surface of the cylinder was not only exposed to the open air, but was coated with a thin layer of cold water, which by the previously acquired heat of the cylinder was immediately converted into vapour, thus cooling it to a great degree, so that a material waste of heat still existed which none of the before-mentioned improvements could remove. Mr. Watt therefore determined on trying the effect of a cylinder with a close top, or one which should effectually shut out the external air, by causing the rod of its piston to slide through a stuffing box, and instead of permitting atmospheric pressure to depress the piston, he made use of steam for this purpose, as well as to produce the vacuum. This expedient he was persuaded he could resort to, because the air's pressure could at no time exceed 15¼lbs. on the square inch, and he knew that the elastic force of steam had been used to a much greater extent in Savery's engine, and could be productive of no danger while it was kept within the moderate limits he required; for since the steam in his new machine had to act against a vacuum under the piston, instead of against the resistance of the open air, so at the heat of 212 degrees it would be fully equivalent to the pressure of the atmosphere; and by using it but a very little hotter it would even be superior to it. His only doubt therefore was, whether this additional expenditure of steam might not occasion a greater consumption of fuel than the waste that occurred through the cooling of the cylinder, but the trial of the experiment set this point at rest, and proved most clearly the value of his suggestion, and in his future engines he carried the improvement so much further, both in the single and double acting engines as they were afterwards called, as to require no more steam for this new mode of operating, than had formerly been required to produce the vacuum only. The machine was now for the first time actually converted into a steam, instead of an atmospheric engine, for atmospheric pressure was entirely excluded, and it worked solely by the power of steam: in consequence of which the cylinder could at all times be kept as hot as the steam which had to enter it, and all the immense loss of fuel that had hitherto attended the use of this valuable machine was completely obviated, while its work was rendered regular and continuous.

The single acting engine, being that which most nearly approached the atmospheric engine which preceded it, shall on this account be first described, and in its description it will merely be necessary to confine ourselves to the construction and form of the steam cylinder, because the boiler, condenser, cistern, air-pump, beam, and counterpoise weights are the same as already noticed, and the particulars of the valves and means of working them will be hereafter described. Such a cylinder is represented by R S Fig. 121, T being its close top, upon which is formed a stuffing box for the piston rod V of the piston U to work through in an air-tight manner, for which purpose it must be well turned and polished, and truly cylindrical. The upper end of the piston rod V is connected to the engine beam as before described, and by means of the counterpoise weights at its opposite end, the piston will be moved to the top of the cylinder, whenever the pipes communicating with it are all open. W is the pipe that brings the steam from the boiler, and delivers it into the upper part R of the cylinder, or by a continuation of that same pipe at X carries it to the lower part of the cylinder S, and Y is the eduction pipe, or pipe leading down to the condenser: *d e f* are valves all opening upwards by external communications, and by means of which certain parts of the steam pipe W X, or the eduction pipe Y can be shut up at pleasure. The valves *d* and *e* are likewise so connected by external machinery that they both move upwards and downwards at the same time, consequently, whenever *d* is down, all steam will be shut off from the cylinder, both above and below, and the eduction pipe will be closed at the same time; but the valve *f* moves independently of them both. If now we conceive the piston U to be at the top of the cylinder and the valve *d* open, while *f* is shut, steam will rush in and fill all the steam pipe X down to *f*, and will at the same time enter the top of the cylinder R, and begin to depress the piston U; and all the air that is contained in the lower part of the cylinder S will escape through *e*, and pass into the condenser to be drawn off by the air pump. When the piston has reached the bottom of the cylinder, the valve *d* must be shut to prevent the entry of any further quantity of steam into the cylinder, and the shutting of *d* will also shut *e* as before observed. Immediately after *d* and *e* are shut, *f* must be opened, when there will be a free communication between the upper and lower parts of the cylinder through the pipe X, and therefore by the mere effect of the counterpoise weights of the beam, the piston U will be drawn to its upper part, and all that quantity of steam that filled the space R will be driven through the pipe X and open valve *f* to the lower part S of the cylinder; thus producing an equilibrium both above and below the piston, by which it is permitted to rise, notwithstanding every part of the cylinder continues completely full of steam. The piston U having arrived at the top of its stroke, the valve *f* must be shut, and those at *d* and *e* opened. By the valve *e* an immediate communication is made with the condenser, consequently all the steam already in the part S of the cylinder will be instantly condensed, and a vacuum made under the piston, while at the same instant a new charge of steam enters the upper part R of the cylinder, to force the piston U downwards which it does with greater ease, because the condenser has previously produced a vacuum in the lower part S of the cylinder, and if the steam gauge of the boiler, (Fig. 111, and page 235,) stands but at 4 inches high, which is a very usual height in working this description of engine, the steam will operate at the rate of 4lbs. more on the piston than the atmosphere could do in an open cylinder, and will consequently produce a greater quantity of work. The piston is carried up again by the power of the counterpoise weights so soon as the valves *d* and *e* are closed, and *f* opened, and by maintaining a constant supply of steam in the boiler, and working the valves in the succession above-described, the motion of the machine may be maintained for any required length of time.

Notwithstanding the steam in this machine has a double operation to perform, viz. that of producing the vacuum, and forcing down the piston; yet by its excellent arrangements no more steam is taken from the boiler than was required by the old atmospheric engine. For all the time that the piston is moving upwards, the boiler is closed and no steam escapes from it; and the quantity that is required for the down stroke is no more, than what was formerly consumed to produce the vacuum and permit the piston to ascend, while the saving that is effected by keeping the cylinder at one uniform temperature, and thereby preventing the waste that formerly occurred, gives it a decided superiority. The large engines erected within the last few years in the neighbourhood of London, at the New River, Chelsea, York Buildings, West Middlesex, and Grand Junction water works, are all on this principle, and most of them possess two engines, the cylinders of which are 64 inches diameter while the length of stroke made by the pistons is 8 feet.

All the steam engines hitherto noticed have their power in in one direction only *i, e*, either in the ascent or descent of the piston, but not in both, and hence they are called *Single Engines*, and though admirably calculated on this account for working simple pumps or otherwise raising water, yet they are unfit to be applied to giving motion to mills or machinery, particularly if that motion is required to be equable and regular. The *Double Acting Engine* however supplies this deficiency, for in it, the steam acts successively on the upper and under side of the piston, and thus renders both its up and down stroke equally effective. Indeed in this machine the power of the steam never ceases except at the instant when the piston reaches the top or bottom of the cylinder, and in order to supply this momentary want of power, and to assist in overcoming the inertia of the piston at the time of its changing its direction, a fly-wheel is always applied to this engine in the manner shewn at Fig. 118, and mentioned at page 268.

The double acting engine requires twice the quantity of steam that would be necessary for a single engine of the same size; but this is compensated for by its doing twice the quantity of work. And after what has been said upon the single engine, little need be added in explanation of the double one, for its principles being the same, a mere change of mechanism is all that is required to produce the machine. No compensation weights are necessary to raise the steam piston, and such an alteration must be made in the valves and steam pipes that a vacuum may be produced by the condenser, alternately above and below the piston, instead of below it only, as in the engines before noticed; the steam likewise must be admitted alternately above and below the piston, at the same moment that the vacuum is formed.

but always on that side of the piston that is opposite to the vacuum.

In order to a due comprehension of the action of the double engine some of the contrivances that have been adopted to produce a proper distribution of the steam, and an alternate vacuum must next be noticed, and although the four-way cock, and sliding regulator are not considered as the most perfect of these, yet they are very frequently applied to small steam engines, and their simplicity gives them a preference. Let Y Z, Fig. 122, represent a section of a steam engine cylinder as before, with its piston, and the piston rod moving through a stuffing box, so as to be quite air-tight, *g* is the steam pipe for bringing steam from a boiler, and this terminates in a four-way cock *h i k*, which, together with the pipes *m n* and *o*, are drawn much too large for the cylinder Y Z, in order that their parts may be distinctly seen: *p* is the end of a lever or handle for the purpose of turning the cock when required. This cock is constructed precisely in the same manner as other cocks for fluids, and consists of a conical plug or pin ground very truly into the body of the cock itself, but instead of having a single straight passage through the plug as is commonly the case, there are two curved ones *h* and *i*, which give the plug the appearance of having four openings, each appearing in the same plane, and at one quarter of the circumference apart, so that as the cock stands in the Figure, steam coming from *g* would pass through the opening *i* in the plug, and would be delivered into the pipe *n* at right angles to its first direction, instead of passing directly onwards to *o* as would be the case in a common cock. From the pipe *n* the steam would pass immediately into the lower part Z of the cylinder, and consequently would drive the piston upwards. At the same time it will be seen that there is an immediate connection between the upper part Y of the cylinder through the pipe *m*, and opening *h* of the cock to the pipe *o o*, leading down to the condenser; consequently so long as the steam is acting against the under side of the piston, there will be a vacuum at Y to permit it to rise. So soon as the piston has arrived near the top of the cylinder, the cock must be turned one quarter round by depressing its handle *p* from its present position to that shewn by the dotted lines at *q*, by which all the openings in the plug of the cock will be changed into the positions shewn at Fig. 123, in which the same letters of reference are used:—steam, therefore, which now enters at *g* will be turned upwards by the passage *h*, and by entering the pipe *m* will be conveyed above instead of below the piston, while the passage *i* forms a connection between the pipe *n*, leading to the lower part of the cylinder, and the pipe *o* leading to the condenser consequently in this position, a vacuum will be formed below the piston while the steam is operating above it. The piston will therefore descend, and on coming near the bottom, the cock must be again turned into its first position, when the piston will ascend, and so on; thus producing an equality of force, both in the up and down strokes, by simply turning one cock, an operation that is effected by the motion of the beam without any other assistance.

One great objection to the use of such a cock as has just been described, (and which was first used, if not invented by Papin) is the magnitude that becomes necessary in the plug in large engines, and which causes so much friction as to require more power to turn it than can be spared. Experience has shewn that in condensing engines about one square inch of area in the steam passage is necessary for each horse power that the engine may be required to work to, consequently even in a 16 horse engine, the openings *h* and *i* in the plug of the cock must be 4 inches square, or 8 inches long by 2 inches wide, which could not be obtained unless the plug were above 6 inches diameter; and with a plug of even this size, when sufficiently close to be steam-tight, the force to be applied to the handle *p* must be very great, particularly at the first starting of the engine. Mr. Murray, of Leeds, therefore, contrived a sliding regulator to answer the same purpose, and which is now very commonly applied to small engines; but in those on a large construction nothing answers so well, and is so effective, as the common conical valve, such as is shewn at *d e* and *f* in Fig. 121. These valves may be made of any required diameter, and as they are merely to be raised perpendicularly from their seats they are very simple, and easily managed. Indeed it is no uncommon thing to make two of these valves work concentrically through each other, the one being above while the other is below, as shewn at *f e* Fig. 121, in which the lower part of the rod *r*, that connects the upper and lower valves *f* and *e* is correctly turned and passes through the spindle of the valve *f*, which is in fact an air-tight stuffing box for it, while the outside of the spindle of *f* is in like manner truly turned, and works through another air-tight stuffing box, as does the spindle of the upper valve *d*. The *Sliding Regulator* is shewn in its two positions, at Figs. 124 and 125, the first being a perspective view of it, as it appears, except that the front is taken away to shew the interior construction, and the second is a vertical section through the middle of the apparatus, which is fixed in the same situation with respect to the steam cylinder, as the cock in Fig. 122, and has the same pipes of communication with the upper and lower parts of it, and with the condenser. In Figs. 124 and 125, *r* is the end of the pipe which conveys steam from the boiler into the small hollow chest or receptacle S, so that it shall always be supplied. One side of this chest *t t* forms part of the pipes of communication to the cylinder, which are usually of an oblong figure in section, and they all open through this side into the chest as seen at *v* in Fig. 124, and at *v u* and *w* in the section Fig. 125. The pipe *v* leads to the lower part of the cylinder, *w* to the upper part, and *u* to the condenser, and the face or side through which these openings are made is ground very flat and true in the inside of the chest. The slider for regulating the admission of steam to the cylinder is shewn at *x x*, and is formed like a box without a lid, and of such depth as to about half fill the chest *s s*, while its length is but just sufficient to cover the ends of two of the pipes, as at *v u* Fig. 125. The edges next the open part of the box or slider are also ground so flat and true that they may slide upon the ground face *t t* in an air and steam tight manner; and in order to produce this sliding motion a turned rod *y y* passes through a stuffing box, and is connected to the slider within the chest. Now since the extent of the slider is only sufficient to cover two of the holes, and the hole *u* is in the center, that hole can never be uncovered, but one or other of the steam passages *v* or *w* must always be open whenever the slider is at the top or bottom of the chest but they cannot both be open at once, because by the time the upper part of the slider *x* Fig. 125, has risen sufficiently to cover the upper hole *w*, its lower part will also have covered and shut up the lower hole *v*, and since steam is supposed to be always entering from *r*, it is evident that it will be directed above or below the piston as the case may be. Thus in Fig. 124, the slider *x x* is at the top of the chest and the lower orifice *v* is open for the passage of steam to the lower part of the cylinder, while a communication will be formed between the upper part of the cylinder and the condenser through the hollow of the slider. And in Fig. 125, the reverse will be the case, for the slider being there shewn in its lowest position, the steam will pass from *r* through *s* and *w*, and from thence to the upper part of the cylinder, while the orifice *v* leading from the lower part of the cylinder will be connected through the cavity of the slider with *u*, the mouth of the pipe leading to the condenser by which a vacuum will be formed. In this way a small vertical reciprocating motion given to the rod *y* by connection with the beam or some part of the moving machinery, is sufficient to produce all the necessary changes in the direction of the steam, so as to maintain the motion of the machine.

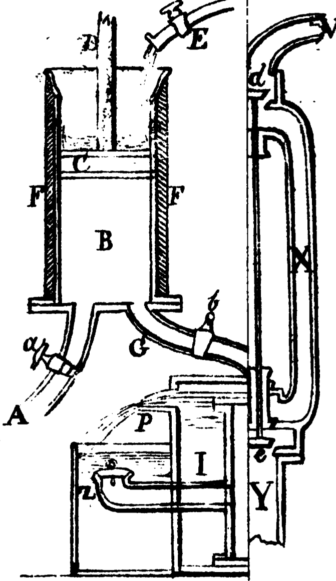
From the nature of the double engine, and its force being continued during the ascending as well as descending motion of the piston, it will be evident that the chain connection with the beam as theretofore used, and as described at p. 259 could no longer be resorted to, for that could only be effective so long as the engine exerted a lifting force alone. The top of the piston rod was therefore converted into a straight rack with teeth or cogs, which worked into similar teeth formed on the circular end or horsehead of the beam; but from the great noise and friction attendant upon this construction, it was soon discarded, and gave way to the more elegant contrivance now universally adopted under the title of *the Parallel Motion Apparatus*, and by which all the defects of the former construction were removed. This apparatus first appeared in the engines constructed for the late Albion corn mills, near Blackfriars Bridge, in 1784.

The difficulty of connecting the piston rod immediately to the end of the beam, arises from that rod being constrained to move through its stuffing box in a right lined direction, while the end of the beam performs a portion of a circle, and therefore disagrees with the motion of the piston rod. Thus if *a* Fig. 126, is the center upon which a beam turns, and *a b*, *a c* be supposed to be the central line of the end or half of that beam, its end will describe the portion of a circle *b d c* in passing from its highest to its lowest positions, and vice versâ, and if *e f g h* represent the right line in which a piston must move, it will appear that the motion of the beam and the piston only coincide at the two points *f* and *g*, for at the points *e* and *h* the piston rod is further removed from the center *a* than the length of the beam *a b* or *a c*, while in the central part of the stroke *d*, the length or radius of the beam is greater than the distance of the piston rod from *a*, and since every beam in moving must deviate from a right line by a quantity equal to the versed sine of the arc through which it moves, so it becomes impossible to attach a piston requiring a right lined movement, immediately to the end of such a beam, unless indeed teeth are used as formerly was the case.

The object of the parallel motion apparatus is to convert the circular motion of the beam, into rectilineal motion; and this may be done by an intermediate piece in several ways. Thus for example, if *i k* Fig. 127, represent a beam turning on a center *k* with any given radius, and *l m* be another beam of similar radius turning on the center *m*, the two vibrating ends *i* and *l* of these beams may be united to an intermediate piece shewn between *i* and *l*, and the piston rod *n* may be attached to the middle of this intermediate piece, and will move in a right lined direction notwithstanding the circular motion of the two beams; for these beams being of equal radius, but opposed end to end to each other, the quantity of versed sine formed by the one will always be equal to that formed by the other, but in contrary directions so as to correct each other; therefore whenever the upper end *l* of the intermediate piece is drawn towards *m*, its lower end *i* will be drawn in an equal degree towards *k*, and thus the motion at the center where *n* is attached will be rectilineal. The parallel motion which is attached to engine beams is however generally in a more compact form, to save room and does not project far beyond the main beam. Thus in Fig. 128, let *p q* be the half of a beam, *p* being the center, upon which it turns while the piston rod is attached to its end *q*, by connection at *r* with the lower end of the intermediate piece between *q* and *r;* in order to produce a vertical right lined motion in this piston rod, another piece *s* is introduced, equal in length to the first intermediate piece, and hung so as to turn upon pivots fixed to the beam between its center and extreme end as at *t;* to the lower part of this second piece, the secondary beam or radius rod *v u* is attached, so that it may turn upon a fixed pivot at *u*, while its length is equal to the distance *p t*, consequently it will produce a vertical rectilinear motion in the lower extremity *v* of the sling or second intermediate piece *s*, and this is communicated back to the point *r*, where the piston is attached, by the bridle rod *w* having pivots working in the lower extremities of *v* and *r*. In this way two right lined vertical motions are produced at the points *v* and *r* whenever the beam moves, consequently, while the steam piston is attached to *r*, the piston rod of the air pump is generally applied to *v*, since they both require perpendicular motion, and although the above apparatus has been described in the singular, it must be understood that similar radius rods bridles and slings are applied on each side of the beam. In some cases, as when double engines are applied to pumping or to working vertical saw mills, a similar parallel motion is applied at each end of the beam. The manner in which the end of the beam opposite to the steam cylinder is attached by a crank to a fly-wheel, to equalise the motion, and supply the deficient power when the piston is at the top and bottom of its stroke has been already sufficiently described by Fig. 118, (see page 268), but when the fly-wheel is required to turn with greater velocity than once for each ascent and descent of the piston, this must be effected by applying the crank upon the shaft or arbor of a toothed-wheel, working into another with a smaller number of teeth, and fixed upon the fly-wheel shaft, from which the power of the double engine is generally conveyed to the machinery it is required to operate upon.

Such is a very general and imperfect account of the important improvements which the steam engine received under the hands of Mr. Watt; improvements which bespeak the truely philosophical and indefatigable mind of their author, who notwithstanding his many other avocations, and his inability to give his whole attention to the subject, was enabled to complete them between the years 1763, when his attention was first directed to the subject and 1769, when he obtained his first patent for these inventions. It is however probable from the vague and uncertain manner in which the specification of that Patent is worded, that Mr. Watt had tried a sufficient number of experiments to assure himself of the value of his invention, and of the truth of his deductions, without being at all perfect in the executive part of his scheme, and without perhaps knowing what might be the best form for the construction of an engine on his principles; for his patent was merely for lessening the consumption of steam, and he describes no instrument or form of machine by which it was to be effected, but says generally, that the cylinder or steam vessel must, during the whole time it is at work, be kept as hot as the steam that enters it, either by casing it with wood, or surrounding it by steam, as now generally practised, or by the application of heat; and that neither water, or any body colder than the steam itself must touch it. That the condensation of the steam must be carried on in a separate vessel communicating occasionally with

page 275 to 290



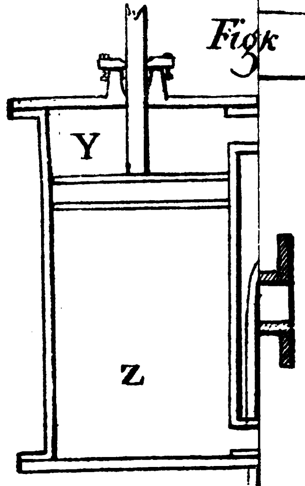


Fig. 126

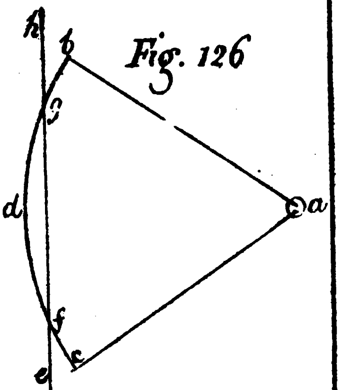


Fig. 127

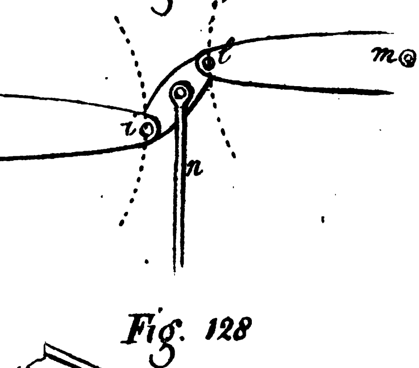
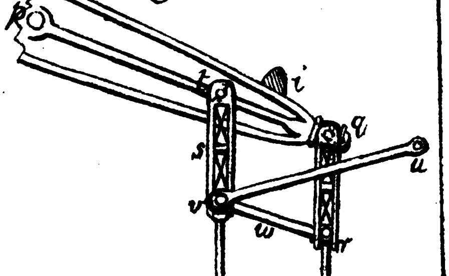


Fig. 128



the steam cylinder, and that the condenser must be kept as as cold as possible. That a pump must be applied to the condenser, to draw off any air or other matter which may not be condensed by the cold. That in some cases he intends to employ the elastic force of steam to act on the piston instead of atmospheric pressure, and that this steam may afterwards be discharged into the air, or may be conducted to the condenser to be condensed; and in other cases he means to cause the steam to act on the floats or vanes of water-wheels so as to produce motion in the same way as by water, except only that these vanes are to be moveable like valves to permit the steam to pass in one direction only. That again in other cases, he should not condense the steam into water, but merely alter its temperature, and work by its alternate contraction and dilation, and lastly, that instead of using water to render the piston and other working parts of his engine steam-tight, he employed oil, wax, resinous bodies, fat, and quicksilver, or other metals in a fluid state.

No sooner had Mr. Watt developed the true principles of steam, and pointed out the manner in which it was to be employed and treated to the greatest advantage, than several other improvements or pretended improvements made their appearance. The very general terms of his specification, however, enabled him to repel his adversaries whatever might be their pretensions. He was even assailed on the ground that his specification did not contain such plain directions as would enable competent workmen to construct his engines when his patent might expire, and no patent has perhaps ever undergone more severe ordeals in the courts of law than his own, but happily for its proprietor it withstood all attacks. Mr. Watt, at the time of making his specification, laboured under very peculiar difficulties, for he had to describe a machine which had never been tried upon a large scale, and with the exact executive construction of which, he was probably then himself unacquainted: for it was not until after he had obtained his patent, that he became associated with Dr. Roebuck, the founder of the immense iron-works at Carron in Scotland, and that he constructed his first steam engine with an 18-inch cylinder, all his former experiments having been confined to mere models. This engine, after repeated alterations, was at length brought to a state of great perfection. About the same period the late Mr. John Wilkinson, of the celebrated iron-works at Bersham, invented a new and more accurate machine for boring large cylinders with a perfection that had before been impracticable, and of this Mr. Watt availed himself with great success. The magnitude of Dr. Roebuck's concerns unfortunately produced embarrassment, and being no longer able to co-operate with Mr. Watt in the manufacture of steam engines, he sold his share in the Patent to Mr. Mathew Boulton, of Soho near Birmingham, who even then possessed a large manufacturing concern which he carried on which great spirit.—Hither Mr. Watt repaired, and began his operations on the grandest scale; and here he ended his days at an advanced age, after contemplating the progress of an establishment which he was himself so instrumental in raising, and which soon acquired a fame for its science and perfection in every civilized part of the globe. It is still carried on with unabating zeal by his Son, in conjunction with the Son of his late associate.

Notwithstanding the exertions that were made by Messrs. Watt and Boulton, to bring the steam engine to perfection, yet from the difficulty of collecting and making the new tools and implements they required, no considerable specimens of the improved engine appeared till 1774, when five years out of the fourteen, for which the patent was granted had expired; and they found, not only from the public prejudice that always exists against new inventions, but the practical difficulties they had to contend with, that their patent must expire long before they could possibly be remunerated for their loss of time, and great expenditure. They therefore applied to parliament for an extension of their term, and the grounds of application appearing manifest, an extension of 25 years from the date of their application in 1774, was most liberally granted to them, so that their patent right continued 30 years and did not expire till 1799.

After the steam engine had thus been perfected, Messrs. Watt and Boulton ascertained by repeated experiments that their engines would perform the same work as those in former use, with only 1-fourth part of the coals that had been formerly consumed. Instead therefore of charging exorbitant prices for their machines, they sold them at fair and reasonable rates, and only exacted 1-third part of the value of their savings during the extent of their patent, which repaid them handsomely, at the same time that it was a most beneficial arrangement for their employers.

Having thus far stated the general history of the steam engine, and the uses of its several parts, up to the period of Mr. Watt's improvements, it now becomes necessary to notice some minor contrivances in this curious machine, and to state a few particulars that were passed over in silence in the general description in order to avoid confusion. In doing this, the most natural order to follow, is to begin with the boiler where the steam is generated, and trace its operation through the entire machine. The boiler itself, so far as it is connected with the production of steam, has been already described (page 266.) But it is so very important a member of the steam engine that it has received great attention from men of science, and some of its improvements are of so curious a nature as to be highly deserving notice. Upon inspection of Fig. 117, Plate XI. which is a view of a boiler with all its appurtenances complete for working it will be seen that several of its parts have not yet been noticed, as for example the feed pipe, the self-regulating damper, and the safety valve, all of which are applied to engines when properly erected and finished. The first of these *The Feed Pipe* is for supplying water to the boiler in order to compensate for that which boils away or passes off in steam. The feed pipe is shewn at *s s*, and passes through a hole in the top of the boiler, where it is fixed in a steam-tight manner, so as to stand perfectly upright. Its lower end proceeds to within an inch or less of the bottom of the boiler, whatever its depth may be, and its upper end which must be of a height proportionate to the strength of steam about to be used, terminates in a small funnel or cistern head, at the upper part of which a spout *t* is placed leading into a waste drain. The feed pipe is open throughout, or without valves from top to bottom, but since it has been shewn (page 185,) that a column of mercury one inch high is equal to one of water of about 13½ inches high, so if the steam has power enough to raise the mercury in the steam gauge *q* to the height of 6 inches it will likewise raise the hot water to the height of 6 feet 9 inches up the feed pipe, but no higher; consequently if the cistern head and spout *t* are about 9 feet high, no hot water can ever escape from that spout, but any water that is delivered into the cistern head, so as to form a column of more than that height will run down the pipe even against the pressure of the steam within the boiler and keep it supplied. For this purpose a very small forcing pump is always fixed, as at *h*, Fig. 120, so as to work in the hot water cistern N, of every engine the motion of such pump being derived from one of the moving piston rods, and thus is the boiler kept constantly replenished with water in a hot state. The feed pipe at the same time offers one of the most effectual safeguards against the bursting of a boiler; for should the steam at any time become too strong, through the inattention of the engine-man, it will in the first place blow all the quicksilver out of the steam gauge *q*, and issue through it with sufficient noise to give notice of the event, and on its becoming equal to a column of water of the height of the feed pipe, it will force all the water contained in the boiler through it, and discharge it by the spout *t* into the waste-drain, thus preventing the possibility of a great accumulation of steam. Still however the feed pipe, as above described, will not regulate the quantity of water to be supplied to the boiler, and hence it becomes necessary to have recourse to the gauge cocks *r r* to ascertain its height. But by a trifling improvement and addition the feed pipe is made to regulate itself as follows; the upper end of the feed pipe is closed by a conical valve *v* opening upwards, and kept down by a weight placed upon it. This valve is attached by a chain to one end of a small lever *u*, from the opposite end *w* of which a wire *x* descends and passes through the top of the boiler by an air-tight stuffing box *y*, so as to terminate in a float *z*, lying upon the surface of the water in the boiler. This float which is usually formed of a flat stone, is so counterpoised by the weight upon the valve *v*, that it just swims upon the water, but raises the valve *v* whenever the water becomes too low in the boiler to support the float at its proper height; consequently so long as the boiler requires no supply of water the valve *v* will remain shut, and any water that is delivered into the cistern head by the hot liquor pump will run to waste by the spout *t*; but so soon as the boiler requires water, the float stone, by sinking, will open the valve *v*, and all the water sent up by the hot liquor pump will run down the feed pipe, because the spout *t* is placed at some distance above the bottom of the cistern head. In the Figure the valve *v* does not appear to close the top of the feed pipe, but shuts into a hole in a false bottom placed in the cistern head, which amounts to the same thing. This false bottom is applied for the sake of the next contrivance to be described, viz. *The Self-Regulating Damper.* A Damper is a sliding iron plate, very commonly applied to flues or chimneys for the purpose of regulating their draught, so as to govern the intensity of the fire; for a damper closes the chimney in a greater or less degree, or shuts it up entirely, and thus permits a greater or less quantity of atmospheric air to pass through the fire, or none at all, by which it is extinguished ; dampers are therefore generally under the controul of those who have the management of the fire, but in the self-regulating damper the fire controuls itself, and is made to burn with more or less violence as it may be more or less wanted in the following manner: *A* is an iron plate or damper of sufficient size to entirely close the chimney or flue *k o*. It slides up and down vertically in iron grooves with as little friction as possible. To its upper part is attached a chain *B*, which passes over the two pullies *C* and *D*, through a tube in the false bottom of the cistern head, and down the center of the feed pipe *s s* until it finally terminates in the hollow or bucket-shaped cast iron weight *E*. When a self-regulating damper is applied to a boiler, the feed pipe usually has a swell or increase of diameter, as at F, the more readily to admit the weight *E* without blocking up the pipe so as to prevent the descent of the feeding water. The weight *E* is so adjusted by filling it partly with lead, that it may just overbalance the weight of the damper plate A, and the friction of the pullies *D C* when the engine is not at work, consequently the damper plate will then always be drawn up, as shewn in the Figure, and the chimney completely open, at which time the weight *E* must rest on the shoulder or projection of the feed pipe at *F*, the chain *B* being properly adjusted in length for that purpose. Things being thus disposed, whenever steam is generated in the boiler, it will press upon the surface of the water and drive it a certain distance up the feed pipe, when the weight *E* by becoming immersed in water, will loose part of its weight (page 156,) and will therefore no longer be able to retain the damper plate at its former height; it will consequently descend, and partly close the chimney by which the violence of the fire will be checked. Should it be too far checked, less steam will be formed, by which the water will rise to a less height in the feed pipe, and the preponderance of the weight E will be restored; while should the fire ever become so violent as to drive the water up unto the cistern head, the weight will be so far raised as to completely shut the chimney. This contrivance is therefore not only of importance in regulating the power of the steam, but in diminishing the consumption of fuel, by never permitting the fire to burn with greater violence than is necessary for the quantity of work to be performed.

Among the most important appendages to a boiler is the *Safety Valve*, for permitting the steam to escape whenever it becomes more powerful than is necessary for the work it has to perform. This has been already noticed (p. 254 and 260) but the form of apparatus shewn at *h i k* Fig. 116, is by no means to be recommended. It is there shewn as consisting of a conical valve *h* pressed into its seat by the lever *i* and weight *k*, which by being moveable admits of different degrees of pressure upon the valve. This form is very useful for experimental purposes, but is by no means fit to be entrusted in the hands of an unskilful workman; for since the power to be required from steam can always be calculated with the greatest nicety beforehand, the workman should have no controul over it, unless indeed to diminish it. Instead therefore of using the steelyard for pressure, the kind of safety valve shewn at *G* Fig. 117, should in all cases be adopted. It consists of a circular conical valve as before, and ought to be sufficiently large. Its superficial area must be carefully calculated in inches, and the highest necessary power of the steam required having also been determined; a fixed and unalterable weight agreeing with such power should be formed and attached to the top of the valve, when the whole should be inclosed in a metal box with a proper passage as at *H* to convey the steam away to the chimney or otherwise. If for example the greatest power of steam required to work an engine should be 6lbs. on the square inch, and the safety valve should be found to contain 6 inches of surface, then 6 times 6 being 36 would give the required weight in lbs. for the load to be placed upon the valve, which would never open until the steam pressed with more than 6lbs. on the inch. The metal box for the valve being locked up, of course no one but the possessor of the key could alter the power of the valve. Another similar safety valve should also be placed upon the boiler, but with rather less load upon it, in order that it may open first, and give notice to the engine-man when his steam becomes too strong, and this second valve may have a rod and handle to it as at *I*, in order to raise it for letting off the steam when necessary, though no such appendage must be attached to the close valve. All boilers should be covered with brickwork or some bad conductor of heat to prevent the condensation of steam by their exposed tops or domes.

Before dismissing the boiler, a few words may perhaps be expected on the nature of its fire-place, and particularly on the means of consuming or burning the smoke of the fire; but the account of the engine itself has become so much longer than was originally intended, that this must be included in the general observation, that all smoke burners consist in different forms for admitting a current of fresh atmospheric air to mix with the smoke in due proportion, at such a part of the fire-place as may be sufficiently hot to produce ignition. The smoke is then instantly converted into flame, and of course the burning of smoke is always attended with a saving of fuel, since it is the combustion of that, which otherwise could impart little or no heat. There are many simple and beautiful contrivances for this purpose, and many patents have been obtained for effecting it. To describe these with justice would alone require a volume. Among the most prominent are those of Robertson, Watt and Boulton, Parkes, Brunton, Jessop, Arnott, &c.

Passing from the boiler we arrive at the steam pipes, which should be sufficiently capacious, and as short as possible, to prevent too much exposure of surface to the atmosphere. They should pass from the upper part of the boiler to the steam cylinder, in a direction greatly inclining upwards, so that any condensed water that forms in them may run back to the boiler, instead of getting into the cylinder, consequently every boiler should (if possible) be set or fixed lower than its steam cylinder, and in order the more effectually to prevent condensation the steam pipes should be coated with haybands, or sawdust and sacking, or some bad conductor of heat, particularly if they are long or much exposed to the air. K L, Fig. 117, shews part of a steam pipe of a proper form to be used when more than one boiler is applied to an engine, which is by no means uncommon when it is in daily use, because the boiler frequently wants cleaning out and examining; and is much more liable to get out of repair than any other part of the engine. Of course therefore should the engine have but one boiler, it must cease to work on such occasions. The dark spot M is meant to show the junction of the steam pipe of the second boiler with that of the first, which takes place above a large conical valve, the handle N of which works through a stuffing box to raise or close it. A similar valve is placed over each boiler, their use being merely to cut off all connection between the boilers, so that if steam were passing from the supposed farthest boiler by the orifice M, it could not enter the boiler shewn in the Figure while the valve N was closed, but would be constrained to pass along the pipe L, common to all the boilers, and which leads to the steam cylinder. As a further preventative of waste of steam, every steam pipe L should contain what is called *A Throttle Valve*, for the purpose of regulating the velocity of the passage of the steam from the boiler to the cylinder, and a section of such a value is shewn at O. It consists of nothing more than a thin plate of metal, made to fit the internal bore of the steam pipe rather accurately, and fixed to a spindle passing transversely through the center of the pipe by steam-tight joints, so that it can be turned round externally by the handle or lever P and set in any direction. If this handle is fixed at right angles to the surface of the plate, then whenever the handle is directly up or down, the plate will present a thin edge towards the steam passage, and will offer little or no resistance to it; but whenever the handle is placed in the direction of the pipe, it will be quite shut and no steam can pass, so that by moving the handle one quarter round the steam pipe will be more or less closed, and the speed of the engine will be regulated accordingly with the greatest nicety. This handle is moved by the hand in engines where the work is regular, but in all cases where an engine is applied to very unequal work, this would be unsafe, and it must be under the more certain controul of machinery. Thus for example when an engine is applied to the rolling of sheet lead the work is excessively hard, and requires the whole effort of the steam, while the metal continues between the rollers; but the instant it leaves them the burthen is removed, and a continuanee of the same power of steam would produce a velocity in the machinery that might threaten its safety. The steam must therefore be instantly shut off or diminished, until the lead is replaced between the rollers for a second operation, and then its full power is again required. All this is brought about by a truly beautiful and philosophical contrivance, called *The Governor.* It is in fact a revolving instead of a vibrating pendulum, and is constructed as follows:—A square iron rod *a b* Fig. 129, Plate XIII. with pivots as its two ends, is fixed up in a vertical direction in any convenient part of the engine house, so that it can revolve on its axis in proper bearings, and such motion is given to it either by wheelwork, or by a cut-gut band passing round a rigger or pulley fixed upon the fly-wheel shaft, or some other revolving part of the engine, and also round the pulley *c*; and the relative velocities of the governor and the engine must be adjusted by such wheelwork, or the respective diameters of the two pullies. Towards the upper part of the rod or spindle *a b*, two bent levers *d e f* and *g e h* are fixed so that they can both turn or open on the common center *e* which is fixed to the spindle; a heavy iron ball *i i* is fixed to the lower end of each bent lever, and the upper ends *d* and *g* of these levers are attached by connecting links *k k*, with joints to the sliding piece *m*, which slides freely on the square spindle. It follows therefore that while the two balls *i i* lie in contact with the spindle *a b*, the slider *m* will be pushed to its greatest possible height upon the rod, but whenever the balls *i i* are opened out into the positions shewn by the dotted lines, the slider *m* must be depressed. The weight of the balls keeps them in contact with the spindle, so long as it remains stationary or moves slowly, but whenever their revolving motion increases, their centrifugal force will drive them to a greater or less distance from the center in proportion to the velocity, consequently, the quicker they move, and the more the sliding piece *m* must be depressed: *l n* is an iron lever turning on the fixed pivot *n*, while its opposite end enters a groove formed in the sliding piece *m*; this is merely for multiplying or increasing the motion produced in *m*, when necessary; for by prolonging the distance between *n* and *l* the end *l* may be made to move in any required degree. To apply the governor to the regulation of the velocity of the engine, it therefore only becomes necessary to connect the end *l* of the lever by means of strong wires with the lever P of the throttle valve Fig. 117, taking care that that valve shall be quite open when the two balls of the governor are lying close to their spindle, for then the engine will move at its full speed. By so doing the balls will instantly separate and raise the end *l* of the governor-lever, which by drawing upon the lever of the throttle valve will partly close it and diminish the speed. Hard work upon the engine will in like manner diminish its speed, and prevent the balls from separating, but the instant it is removed, the additional speed of the engine will raise the balls and produce the same retardation, until by the introduction of fresh work, the speed becomes so much more diminished as to permit the balls to descend again. By means of the governor an engine under very unequal work may be made to operate with very nearly the same regularity as if its load was quite equable.

The steam pipe ends next the cylinder either with the four-way cock (page 283.) The Sliding Regulator (page 285,) or a system of conical valves, such as were described to appertain to the single-acting engine (page 280.) From these the steam is distributed into pipes leading to the top and bottom of the cylinder and the condenser, called *The Side Pipes*, the form and disposition of which must be sufficiently obvious from what has already been said upon them, and inspection of Figs. 121, 122, and 126. The side pipes of the double-acting engine have not however been noticed when valves are used, as is always the case in large engines, but their form and use is as follows:—*o* Fig. 130, is the pipe conveying steam from the boiler, and delivering it into the descending pipe *p*, which terminates in the valve *q*, opening to the lower part of the cylinder by the side opening marked as a shaded parallelogram, while the valve *r* opens a similar communication with the upper part of the cylinder, so that by the successive opening and shutting of *q* and *r* steam is admitted above and below the piston: *s* is the lower end of the eduction pipe joining on to the condenser H, and this pipe opens first to the lower part of the cylinder by the valve *t*, and leads also by a perpendicular continuation of the same pipe *v* to a valve *u*, by which a connection is formed with the upper part of the cylinder. The two apertures into the cylinder called *Nozzles* are therefore common both to the admission of steam, and formation of the vacuum which is regulated simply by the working of the valves. For as the Figure now stands *r* is the only open valve in the steam pipe, consequently steam would enter above the piston to depress it, while a vacuum would exist below it on account of the valve *t* being open to the condenser. As soon as the piston reaches the bottom of the cylinder, the valves *r* and *t* must be shut, and *u* and *q* opened, when the steam being no longer able to get through *r* would pass down the pipe *p* and enter the lower part of the cylinder through *q*; meantime *u* being open to the condenser by the pipe *v*, would cause the necessary vacuum above the piston to permit its ascent, which being completed, the valves must be again put into the position shewn in the Figure to produce its descent, and so on. To describe the particular manner in which these valves are moved, would occupy much time, and would far exceed the limits of the present work which does not pretend to enter into such minute practical details, as may serve for directions to a workman in the construction of a steam engine, but merely to point out the general principles of its action. It will therefore be sufficient for this purpose to state that these valves are operated upon, either by levers passing in a steam-tight manner through the side pipes, or that sometimes the spindles of the valves are made to act one through the other in stuffing boxes as mentioned in describing Fig. 121, (page 285), when they are worked by external applications. It is likewise not unfrequent to connect a steam and condensing valve, when they are required to open and shut simultaneously by an external rod, as shewn in that Figure. Motion is communicated to the valves in such engines as are without a fly-wheel, by a rod or beam attached to the engine beam very near to the cylinder end of it, and called a *Plug Tree.* This plug tree is equipped with certain adjustable projections called *Tappets,* which strike the levers or handles of the valves, and thus open and shut them at the proper intervals as they rise and fall with the beam. But in all engines with fly-wheels it is deemed better to apply an excentric piece or wheel upon the fly-wheel shaft *x* Fig. 118, and this by its revolution, alternately pushes and withdraws a rod connected with it, and thus provides ample means of giving proper motion to the valves. Such an apparatus is shewn at Fig. 131, in which *w* is a cross section of the fly-wheel shaft, and *x* the excentric wheel fixed upon and revolving with it; a circular rim of metal *y y* encompasses this excentric-wheel in such manner as to permit its turning round, and from this rim two long arms *z z* project, and are braced together to encrease their strength. They terminate in one rod *a* upon which the tappets *b c* are fixed, while *d e* is supposed to be a lever connected with the cock or valves of the engine, and which requires to be turned partly round upon its center *e*; while the excentric-wheel *x* remains in the position shewn in the Figure, neither of the tappets *b* or *c* can have any power upon the lever *d*, but by the revolution of the fly-wheel shaft, the excentric will alternately be brought into the position shewn by the dotted circle, and one exactly opposite to it, consequently the rod *a* will be made to slide backwards and forwards, and each of its tappets will in turn give such an impulse to the lever *d* as will move it the required distance. Every engine maker has his favourite manner of moving the valves, and as scarcely any two engines will be found alike in this particular, it is in vain to attempt more than a general explanation of this part of the machine.

From the side pipes we pass to the steam cylinder, respecting which it will only be necessary to observe, that it is now constantly bolted very strongly down to a massive platform of brickwork or masonry, called the *Cylinder Wall*, and by which it is kept perfectly steady. Its inside is very truly bored and polished, and the apertures by which the steam enters it are placed as near as possible to its top and bottom, and are never made circular, but are long parallelograms, in order to give as much steam passage as possible without abstracting from the length of the cylinder; for the piston must in no case cover these holes, otherwise the passage of the steam would be stopped, while if too great a space was left above and below the piston much steam would be wasted. The steam passages are therefore very frequently formed in a protuberance above the top and below the bottom of the cylinder, instead of passing through the side of it; and in this way they are completely removed out of the way of the piston. In small engines the outside of the cylinder is cased with wood or flannel, but in the larger sorts a hollow metallic and air-tight casing surrounds the whole cylinder at a short distance from it, and the space between the two is supplied with steam from the boiler by a small pipe for that purpose, by which the cylinder is kept as hot as the steam that enters it. Engine cylinders being generally of considerable height, are usually surrounded by a gallery at 3 or 4 feet from their tops for the workmen to stand upon while packing the piston, or performing other repairs.

The piston moving within the steam cylinder, formerly consisted of two circular plates of iron attached together by screws, which at the same time served to retain the hemp or other packing placed between their exterior edges, to make them air-tight, and as the force operating upon the piston was constantly acting downwards it was merely suspended from the piston rod by iron straps or chains, as shewn at *d* Fig. 119. Now that the force is applied from below as well as above, the piston is differently constructed and attached, as shewn in Figs. 120, 121, and 122, for a much larger quantity of packing is introduced between the top and bottom, and instead of these being mere plates they are formed as shewn in Section at Fig. 132, by the two parts *f f* and *g g*, usually of cast iron. The lowest part *f f* is turned into the shape shewn in the Figure, so as to form part of the groove *h h* for the packing to lie in, and the upper part *g g* when placed in its proper situation completes that groove, but as a certain portion of the upper part of *f f* is made cylindrical the top *g g* fits upon it like the lid of a box, and the two pieces are held together by the screws *i i*, by means of which their distance asunder can be regulated. The packing *h h* consists of loose or unspun long hemp, which has been hackled, and is wound round in the groove, while the two pieces *f f* and *g g* are at the greatest distance asunder which the screws *i i* will allow of, so as to keep their hold; and the packing being made as solid and close as possible, the piston is introduced into the cylinder, when the screws *i i* are tightened in order to bring the piston top and bottom into as close contact as possible, and this by their particular form has the effect of squeezing out the packing, and causing it to press forcibly against the inside of the cylinder. Indeed when the packing wears so as to become too small by use, these screws, which are more or less in number, according to the size of the piston, are always resorted to for tightening it, so long as they are capable of acting; and when this is no longer the case, the piston top must be removed and an additional quantity of new packing introduced. The piston rod is attached to the bottom part *f f* of the piston by passing it upwards into a conical hole made to receive it, and which is exactly fitted by the bottom of the rod, while a screwed nut *m* placed between the top and bottom draws it upwards and effectually secures it. As the piston itself, and the cylinder top which must be removed to get at it, are both of considerable weight, it is customary in all large engines to place a crane or crab in some convenient situation above the cylinder for facilitating these operations. Mr. Arthur Woolf with a view to render the necessary removal of the cylinder lid less frequent, contrived a piston in which the motion given to one of the screws *i i* was communicated to all the rest by toothed-wheels attached to the top of the piston within it, so that a large key, like a watch key, might be introduced through a hole in the cylinder lid to act on this one screw, and by it, all the other screws in the piston rod could at any time be tightened. At other times this hole was closed by an air-tight screwed plug. The cylinder lid has likewise a cavity formed upon it to contain tallow, which is melted by the heat of the steam, and occasionally introduced into the cylinder by a funnel with a stop cock, to keep the piston steam-tight and diminish its friction. The packing round the piston rod, and indeed in all the stuffing boxes, is formed in like manner of loose hemp moistened with tallow, and occasionally screwed up to increase its pressure.

Sometimes with a view to save the trouble and expence of frequent packing, the piston is made altogether of metal, and brass seems to answer best for this purpose, particularly when the cylinder is of cast iron which usually is the case. The metal piston of the Rev. Dr. Cartwright has been much used for this purpose and is found to answer very well. It consists of two rings of brass of the full size of the cylinder, which are cut into several segments, as shewn at *l l l l* Fig. 133, and laid one above the other so as to *break-joint*. The joints therefore in the under-ring are shewn by dotted lines in the Figure, and being thus disposed the two rings are secured in their places by a top and bottom plate, to which the piston rod is fixed, as at Fig. 134. The segments are pushed away from the center by steel-springs, shewn at *n n n* Fig. 133.

One of the best pistons of this description is shewn at Fig. 135, and consists of one thick ring of brass *o p q* instead of two as in the last case. This ring of course very nearly fits the cylinder, and is first cut into the form of the equilateral triangle *o p q* by taking off the three segments *r r r*. The triangle next has its three points cut off so as to form three smaller triangles *s s s* when the central piece is discarded, and the three segments and three small triangles *r r r* and *s s s* are secured between plates, as in the piston last described, and lastly, three springs *t t t* press outwards from the piston rod *v* against the backs of the triangles *s s s* which act as wedges to press the segments against the inside of the cylinder, and as these wear by use the points of the wedges themselves protrude, and being formed of the same metal, still make part of the piston. A piston of this description has been known to work for many years without requiring any other attention than keeping it properly greased, and for a true cylinder, it is one of the best forms that can be adopted particularly in high pressure steam engines.

From the piston rod, which is always of wrought iron, and most carefully turned, the power of the steam is conveyed to the beam through the medium of a parallel motion apparatus, as shewn at Figs. 127 and 128, and little need be said upon the beam except to notice that although it is sometimes made of timber as was formerly the constant practice, yet it is now much more frequently constructed in cast iron in a parabolic form, and strengthened at the same time that it is ornamented by projections or mouldings, such as are shewn in Fig. 128. The beam is usually cast in one piece, but in very large and powerful engines it is formed of two parallel cheeks placed a few inches asunder, and in this case, all the piston or connecting rods not requiring parallel motions are connected between the two cheeks. In double engines with fly-wheels no precaution is necessary to limit the motion of the beam, because this is most effectually done by the length of the crank; but in single engines when no crank is applied, a very strong piece of timber is bolted across the top of the beam, as at *i* Fig. 128, so as to strike against two very strong timber springs placed on each side of the beam, and supported near the middle of the two principal beams which carry the center *k* of the engine beam, and which are on this account called the *Spring Beams* of the engine. The springs are covered with cork at the place where they receive the blow to prevent noise, and they communicate with a bell which they ring when struck too violently, in order to give notice that the tappets, by which the steam valves are opened, are misplaced, aud these must accordingly be altered, so as to shut off the action of the steam at the exact moment when the beam has completed its proper stroke. In some small engines the beam is made in two halves, and of a triangular form, one half being applied on each side of the machine, below the cylinder instead of above it, in which case the machine is called a *Bell Crank* Engine from the similarity in the action of this apparatus to the cranks used in hanging bells.

Descending again from the beam and cylinder we arrive at the condenser H Fig. 120. Of this it has been before observed, that it is placed in a cistern of cold water I I, which is constantly replenished by the cold water pump O. It was however soon found that a mere immersion of the condenser in cold water did not produce a sufficiently rapid condensation for the purpose of the steam engine, and it therefore became necessary to introduce a very small jet of cold water into its interior which is done by what is called the *Injection Cock*. The situation of this cock is shewn at *g* in the Figure, being placed under the surface of the water in the cistern I I, and in such a position that the jet of water thrown into the condenser may meet the steam on its entrance. The injection cock is turned or opened by a long spindle fitted upon it, and passing upwards through the floor of the engine house, until it terminates in the small handle or lever *i*, which acts as an index, and moves over a small graduated brass circle to show in what degree the cock is opened, or when it is closed; because since the condenser is in a state of vacuum when the engine is at work, a very minute turning of the cock will produce a great difference in the quantity of water discharged into it. The importance of the injection cock is such that in some engines for steam-boats, where from the motion of the sea it has been found impossible to maintain the water of the cold water cistern at its proper height, the condensation has been wholly effected by the injected water, supplied without a cistern. The vacuum in the condenser is produced jointly by the condensation of steam, and the action of the air pump K, and as it is important to obtain this vacuum as perfect as possible, so it becomes necessary to have some means of judging of its state, and ascertaining whether the air pump is in proper repair and is doing its duty. This is done by what is called *The Barometer*, which consists of a small air-tight iron tube proceeding from the upper part of the condenser, and terminating in a glass tube of 32 inches long, fixed against the wall of the engine house, or in some steady place, and filled with quicksilver. The lower or iron part of this tube may be of an indefinite length, but its upper part to contain the quicksilver is bent into the form shewn at *k* in the Figure. Its operation being precisely similar to the syphon gauge of the air pump (page 105) must be sufficiently obvious without further comment.

There is one more appendage to the condenser, called *The Blow Valve*, which must be noticed, as being quite necessary to starting or giving the first motion to the engine, though it afterwards becomes passive and useless. This valve is shewn at Z Fig. 120, and consists merely of a conical valve opening outwards at the end of a pipe leading to the inside of the condenser, and placed likewise in a small detached cistern of cold water. Its use is to produce the first vacuum before the engine begins to move, for since there is much more friction to overcome, while the grease in the piston packing and that of all the stuffing boxes is cold, than there is afterwards, so if steam were merely applied on one side of the piston before a vacuum had been produced upon the other, it would be next to impossible to get the machine into motion. In order therefore to start an engine the injection cock *g* of the condenser must be shut, and all the other valves opened at once, which is always provided for in the mechanism of the valves. By this, the steam will not only pass into the cylinder above the piston, but below it, and into the condenser at the same time, and this is called *Blowing Through* the Engine. It must be continued until all the parts get sufficiently hot to put them in a proper state for working, and the superfluous steam, as the parts become heated, will pass off and escape through the blow valve, which is lifted by the force of the steam, and placed under cold water in the cistern Z, that it may be condensed as it escapes, instead of filling the engine house with steam. It is this blowing through that produces the very loud noise experienced in starting large engines, and it occasions a small waste of steam for a few minutes which cannot well be obviated. So soon as the engine is sufficiently heated, the side pipe valve, which permitted the steam to pass into the condenser, must be closed, and the injection cock *g* opened by turning its handle *i*, when a vacuum will be instantly formed in the condenser, and of course on the opposite side of the piston to that on which the steam is still permitted to act. The piston will therefore begin to move, and having made one or two strokes, every part of the engine will become properly heated and will continue its motion. But should this not be the case, the operation of blowing through must be repeated until it does work properly, after which the blow valve becomes useless, and is not detrimental to the operation of the condenser, because it will constantly be kept closely shut down by atmospheric pressure.

The uses of the other parts of the engine, such as the air pump K which discharges its hot water into the small cistern N, and the cold water pump O, for keeping the cistern I I constantly filled, need no further explanation, because there is nothing peculiar in their construction. The small forcing pump *h* working in the hot water cistern N supplies the boiler with hot water, which it delivers by its ascending pipe *p* into the cistern head of the feed pipe *s s* Fig. 117, (page 294,) and this water being chiefly produced by condensed steam contains little or no air which renders it preferable to any other.

In the early construction of steam engines, even after they were improved by Mr. Watt, it was customary to let the steam act on the piston during the whole of its passage from one end of the cylinder to the other, by which the motion of the piston was found to become accelerated so as to be most rapid at the moment when it was required to stop.

This was detrimental to the engine, not only on account of the irregularity of the motion; but from the great quantity of momentum that was neccessarily generated, in the piston, the heavy beam, and in fact, in all the moving parts of the machine, and which required to be destroyed between each stroke, at a great sacrifice of power. Mr. Watt however found that he could render the motion of the piston regularly progressive instead of accelerated, by gradually shutting off the steam, long before the whole motion was completed, and that with the momentum previously acquired (and which, if continued, would have produced detrimental acceleration) the elasticity of the steam before admitted would complete the stroke of the piston. This turned out to be an excessive advantage in point of expence, for instead of consuming a whole cylinder full of steam to produce each motion of the piston, it was found that half this quantity was nearly as effective, in consequence of which Mr. Watt obtained a separate patent in 1782, for this mode of applying steam. In his subsequent experiments (in which he was corroborated by Professor Robison,) it appeared that one quarter of a cylinder full of steam performed 3-fifths of the work that the whole quantity would have done; so that by shutting off the steam when the cylinder was from one quarter to one half filled, very nearly the same quantity of work was done, and that with a much more agreeable motion than when the whole quantity was used.

This circumstance is of the greatest importance in regulating the power of an engine to variable work, since by altering the arrangement of the hand geer, the engine may be made to shut off its steam either at the end of its stroke, or any earlier period. This mode of using steam is now constantly employed, and accounts for the observation before made, that the four-way cock or slide valve are not the most perfect contrivances for distributing the steam (page 666,) because in both these, the instant that a vacuum is formed on one side of the piston, steam is admitted, and continues to act on the opposite side, until by their motion the operation is reversed; while with the separate valves shewn in Figs. 121 and 130, the steam may be shut off in any part of the stroke, while the vacuum can be maintained until the piston reaches the end of the cylinder. In large engines where the cylinder contains several hogsheads, this produces a material saving, but in the smaller ones where the cylinder holds but a few gallons it is of less importance.

The safety of the several parts of an engine, and the accuracy of its motions all depend upon the correct opening and shutting of its valves at the proper instant, for if they were to remain shut at the time when they should open, or be open when they ought to be shut, considerable mischief might arise to the engine from the steam being permitted to act in a wrong direction by which the piston might be driven against the top or bottom of the cylinder. In the construction of hand geer particular attention must therefore be paid to these circumstances, and the more particularly, because in practice the valves have a constant tendency to stick or remain closed when once they are shut, and the means which is through necessity adopted to counteract this effect, tends to open them at improper times. The reason of this defect will be apparent on inspecting any of the Figures in which valves are introduced, Fig. 121, for example, in which the valve *f* is represented as shut. If now the engine be considered as at work, steam will be pressing upon the upper part of that valve while a vacuum will exist below it, consequently it will be very forcibly held down in its seat; so forcibly indeed that no ordinary power could raise it; for if this valve is 10 inches diameter (being the size used in the large water works engines before noticed page 281), and the joint power of the steam and vacuum is equal to 15lbs. on each square inch; the valve will be held down with no less a force than 1125lbs.; and even when the valves *d* and *e* are closed, still the vacuum will continue under it; so that before it can be opened for the admission of steam under the piston, this enormous force must be overcome. When *f* is opened, the valve *e* will be shut under the same circumstances, since it will have a vacuum below and a similar pressure of steam above it; consequently, some expedient must be resorted to for the reduction of this force, or the valves and hand geer would be incapable of resisting it. In engines under 30 horses' power the valves are therefore opened by what are called *Plunger Weights*, instead of by the hand geer, the only office of which is to release them at the proper moment, and afterwards to shut them by raising the weights. The plunger weights are made sufficiently heavy to overcome the resistance of the valves, and they are attached to their levers by straight rods in such manner as to keep the valves constantly open; of course whenever a valve is to be shut, its plunger weight must be lifted by the engine, and latches or spring catches are applied to the levers of the valves, so as to retain them in their shut position, and prevent the possibility of their opening again until these catches are released by the action of the hand geer. Such an arrangement applied to one valve only, in order to prevent confusion in the Figure is shewn at Fig. 130, where *w x y* represents the lever or handle of the valve *q*, turning on a pivot *w*, which passes in a steam-tight manner through a square part or cavity in the side pipes, formed purposely to contain the valves, both above and below. From the part *x* of this lever, the plunger rod *x z* descends perpendicularly, and terminates in the plunger weight *a*, which must be heavy enough to overcome the pressure of the steam on the valve *q* when shut, and to open it by drawing its handle down into the dotted position *w b*; *c* is a stud or projection also fixed to the pivot of the valve in such manner as to move with it, or to prevent any motion in the valve when it is fixed, and *d e* is a latch or catch turning on a center, but kept in its horizontal position, as shewn in the Figure by a spring. When the valve *q* is shut the stud *c* is in such a position that it lodges against the flat head of the latch *d*, and keeps that valve closely shut and its lever in the elevated position *y*. No steam can therefore pass through *q*, but since the upper steam valve *r* is open it will enter the upper part of the cylinder and cause the picton to descend: *f g* is the lower part of the plug-tree beforementioned, the upper part of which joins the beam, or is connected with the piston rod, so that when it rises or falls the plug-tree will do the same, consequently, under the present circumstances, it will be making its down stroke; *h* is a tappet or adjustable pin fixed upon it, and this must be so placed that when the piston has completed its down stroke, that pin may come into contact with, and depress the end *e* of the catch, by which its opposite end *d* will be sufficiently elevated to let the stud *c* pass under it, which it will do in obedience to the weight *a*, and thus open the valve *q* and throw its handle into the position *w b*. By this same motion the upper steam valve *r* is also closed, consequently the piston will immediately change its direction and begin to ascend, in doing which it will take the plug-tree with it, until another pin or tappet fixed upon it at *i*, comes under the depressed end *b* of the valve handle, and lifts it into its former position *y*, in doing which the end of the stud *c* will be pressed against the inclined plane formed on the under side of the latch at *d* by which it will be enabled to lift and pass it, so as to become once more locked in its former position; and as the shutting of the valve *q* opens that at *r*, so of course the piston will begin another descending stroke. After this explanation, it will be easy to comprehend how the condenser valves may be acted upon by similar machinery.

The sudden descent of a weight sufficiently heavy to open the valves of a powerful engine, would be attended with serious inconvenience, was not some expedient resorted to for diminishing its force. To do this, each plunger weight moves in a strong box or case *k k* which very nearly fits it, and as this, together with the weight itself is placed in the cold water cistern, of course, this box is always filled with water, which is admitted by a valve *l* opening inwards; when the plunger weight descends, it is therefore resisted by the water which only permits it to move slowly; but in its ascent, the valve *l* opens and admits of the most rapid motion, and at the same time prevents any unnecessary load being thrown upon the Plug tree, which is further assisted by the lever from *x* to *y*, being much longer than from *x* to *w*. In engines of great power, the weight of the plunger would necessarily be so great as to be very inconvenient, and Messrs. Watt and Boulton have therefore most ingeniously applied a small separate steam cylinder and piston for the express purpose of removing the pressure from the valves. The piston rod of this small cylinder, which is usually fixed immediately below the side pipes, is a continuation of the rod by which the valves are connected, and is made steam tight by working through stuffing boxes. The piston is of the same diameter as the valves to which it is connected, and the steam passages are so continued from the side pipes, that when steam is made to press on the upper side of any valve it is at the same time admitted below the piston, and thus tends to raise that valve upwards with a force exactly equal to that which presses it downwards consequently the valve moves with the same facility as if it were in the open air. The plunger weights do not therefore require to be of greater weight than what is necessary to overcome the friction of the piston, and the stuffing boxes of the valve spindles. In those engines that work with a four way cock, or sliding regulator, plungers are unnecessary, and indeed cannot well be applied, though the motion they produce is always desirable, becuse the steam cannot be cut off too suddenly, but should be admitted gradually; for if its power is too suddenly thrown upon the piston, it may do mischief by its exertion before the vis inertia of the piston and beam are overcome. The slider and cock are likewise subject to another inconvenience, namely, that if the first of these is applied to an engine of too much power, the sliding box *x x* Fig. 125, will be so powerfully pressed against the face *t t*, by the constant action of the steam on its outside, and the vacuum within it, that the rubbing parts soon wear into inequalities and cease to be steam-tight, and sometimes from the same cause, the slider sticks, or requires great force to move it. The cock likewise Figs. 122 and 123, from only turning one quarter round, and then back again looses its round figure by wear, and ceases to be steam-tight by becoming irregular. This defect was removed by the late Mr. Joseph Bramah who caused the cock to turn continually round in the same direction, by a slight alteration of the stud that acted on its lever *p*, and which drove it one quarter round at each stroke. This by inspection of the Figure will be found to produce the same effect as moving it backwards and forwards, but with the advantage of causing it to wear equally in every part.

After having thus described the several parts of a double-acting steam engine in their separate states, it will merely be necessary to repeat their names in referring to Plate XIV.*

* The Frontispiece.

which is a general view of a complete engine of this kind as they are now very frequently made for the purpose of rendering them perfectly independent and unconnected with the building in which they may be placed: *a a* is a long narrow box or case formed by screwing plates of cast iron together so as to form a base or support for the whole machine to rest upon. A part of this base is furnished with a close bottom as from *b* to *b*, and an upright partition at *c*, so as convert the part *a b b c* into the cold water cistern. Immediately over this cistern the steam cylinder *d* is fixed, and directly under it the condenser *e*, and air pump *f*: *g g* are the side pipes receiving their steam from the steam pipe *h*, which proceeds from the boiler A, and this is equipped with all the several contrivances, shewn in Fig. 117: *i i i* are cast iron columns, four of which are placed in the angles of the base to strengthen it, and two in the center. They are for supporting the entablature plates or spring beams *k k* upon which the beam *l l* is mounted, and to which the radius rods of the parallel motion *m* are attached; *n* the piston rod of the steam cylinder, and *o* that of the air pump, which in this instance also operates as the plug-tree, by carrying the two tappets *p p* which act upon the lever *r*, for admitting or shutting off the steam. The hot water cistern is shewn at *q*, *s* being the hot water pump, and *v* the rod by which it is worked from the main beam; *u* is the cold water pump worked in a similar manner: B the fly-wheel, the shaft or axle of which is supported on the top of the base *a a* while its crank works within it, and is connected by the connecting rod C with the end of the beam: *w w* is the governor,worked by the line 1 1, and operating on the throttle valve *x* by the rods 2 2: *y* is the handle and index plate of the injection cock, and *z* the barometer of the condenser, fixed against one of the iron columns. The parts of the boiler need scarcely be referred to again, but 3 is the man-hole, 4 the feed pipe, 5 the fire place, 6 6 the chimney, 7 the gauge cocks, and 8 the steam gauge.

It will be obvious to any one who contemplates the nature of Mr. Watt's improvements in the steam engine that they are susceptible of many forms and applications: and indeed a Mr. Jonathan Hornblower actually obtained a patent in 1781, (being some time antecedent to Mr. Watt's last patent for using the elastic force of steam,) for a process that was highly ingenious, though probably without his knowledge it had been previously described by Dr. Falck. Mr. Hornblower's plan was to use two steam cylinders and pistons instead of one, although no additional quantity of steam was required; for the cylinders were connected by pipes with cocks or valves, in a manner something similar to what is shewn at Fig. 136, Plate XIII. where *a b* is the ordinary cylinder of a double engine, supplied with steam as before described by the pipe *c*, which has two cocks *d* and *e*, or any of the contrivances before spoken of for properly directing and distributing the steam. Cocks are made use of in this Figure as being the most simple, and for the same reason no preparation is made for turning them at the proper periods by machinery, but they must be conceived to be opened and shut by the hand. Pipes *f* and *g* likewise proceed from the upper and lower parts of the cylinder for the escape of the steam; but instead of leading to the condenser, as in the engines before described, they lead into the reverse parts of another steam cylinder; that is to say, the pipe *f* from the upper part of the first cylinder leads into the lower part *h* of the second one, while the pipe *g* connects the lowest part of the first cylinder to the highest part of the second. This second steam cylinder is longer, and otherwise of larger capacity than the first, and from its upper and lower parts the two pipes *k* and *l* proceed, and terminate in the condenser *m*, as in other engines. All these several pipes have cocks or valves by which they can be opened or closed at pleasure. To work this machine, all the cocks or valves must be opened at once to blow through or fill every part of the engine with steam, after which the steam cock *d*, and the cocks in the pipes *g*, and *l* must be shut at the same moment, and the injection cock of the condenser opened. The steam will then enter *b*, and begin to raise the first piston *n* while that steam which was already in *a*, will pass by the pipe *f* to *h*, and will consequently exert its remaining elasticity to raise the second piston *o*, above which a vacuum has been formed by connection with the condenser *m* through the pipe *k*; and as both the pistons are attached to the same end of the beam, of course the power produced by them will be exerted at the same time, and in the same direction. The pistons having gained the top of their stroke, the steam cock *e* must be shut, together with the cocks in the pipes *f* and *k*, and all the others opened, when their former action will be reversed; for now steam will enter *a* to depress the piston *n*, and that which was already in *b* will exert its elasticity and pass through the pipe *g* into *i* to depress the piston *o* while a vacuum is formed in *h* by the opening of the pipe *l*. The pistons will therefore descend simultaneously, and by such means Mr. Hornblower expected to have derived great practical advantages in which he was corroborated by the mathematical investigations of Dr. Robison, who estimated that this machine would possess a power over the engine of Mr. Watt, in the proportion of 863 to 833. This however proved to be one of these cases in which the true investigation of the power could not be made to agree with the practical result, for after a very fair trial of this engine, (several having been constructed on a large scale,) it was found that the friction of two pistons, and the great additional surface that was exposed to cold, more than compensated for the advantage of this mode of applying steam, at least as it was then done; for it has since been ascertained that steam of great heat and high elastic force may be worked with considerable advantage in this manner.

The engine of Mr. Hornblower was however ineffective without the condenser, close cylinder, and other improvements which had been secured to Mr. Watt by his previous patent, of which it was deemed to be a direct infringement on the trial of the case at law; consequently Mr. Hornblower was reduced to the necessity of recurring to the old plan of condensing in the large cylinder, and by this the advantages he might otherwise have obtained were quite lost, and his contrivance became useless and unavailing.

Although Mr. Watt adopted the use of steam instead of atmospheric pressure, yet in all his various constructions he confined its elastic power to a force very little exceeding that of the air, at which it may be worked with perfect safety. But the early experiments that had been tried on engines convinced engineers that boilers might be made to withstand very considerable pressure, and if such surprising effects were produced by steam in a weak state, what might not be expected from it when its. force was accumulated? Such reasoning led to the construction of what are termed *High Pressure Engines*, or those in which the steam, by additional heating and confinement is increased in its elastic power, so as greatly to exceed the pressure of the atmosphere. The operation of such an engine needs but little explanation, for since steam at 212 degrees is a balance to the atmosphere, or will appear without force in the open air, but will move a piston into a vacuous space with a power of from 14 to 15lbs. on the square inch; so if that steam be doubled in its power or made equal to 30lbs. on the inch, by heating it to 245 degrees, it will exert the same power against a piston moving in air, as the former steam did against a vacuum; consequently, by increasing the power of the steam, the construction of the engine may be very much simplified, for the condenser and its cistern, the air pump, the cold water pump, and all those parts that are concerned in forming the vacuum may be entirely dispensed with, and much friction saved. This is of the greatest importance in situations, where the requisite quantity of cold water for effecting condensation is procured with difficulty, and this, in many instances, has proved a complete barrier to the introduction of an engine where it might have proved highly useful.

The first application of strongly condensed steam to the motion of pistons appears to be that mentioned in *Leopold's Theatrum Machinarum,* 1724, and is attributed to Dr. Papin; but it does not seem to have been successfully carried into effect until applied by Mr. Richard Trevethic of Camborne in Cornwall, who, in conjunction with a Mr. Vivian, of the same place, obtained a patent in 1802, for a form of engine which has been much used and approved on a small scale, and is very generally known by the name of *Trevethic's Engine.*

The construction of a high pressure engine is so closely allied to those of Savery and Papin, (see Fig. 115, Plate XI.) that it requires but a very small extent of inventive genius to convert either of these, and particularly the last with a cylindrical steam vessel, into such a machine; for we have only to suppose the circular piece of wood already mentioned as floating on the water in that vessel (page 255) to be a steam-tight piston equipped with a piston rod passing to the outside of the vessel, and the engine will be formed; for the force that was then described to be acting to depress the water, will now depress that piston, the power of which may be transferred to any other purpose. Mr. Trevethic's contrivance however goes much further, and embraces an entire construction of engine in which great simplicity is preserved, and considerable ingenuity displayed. His principal view in its application, as declared in his patent, was that of forming an engine so compact, portable and independent as to be capable of being applied to the moving of carriages on rail roads. This great object he was enabled to effect; and there cannot be a higher proof of the perfection of his plan, than its having been successfully applied since the year 1812, to the transportation of coals from several collieries near Leeds, Wigan, and Newcastle upon Tyne. One loco-motive engine of this description, has been known to draw 30 waggons of coals, each weighing above 3 tons, along a level iron rail road, at the rate of 3½ miles in the hour; and the joy with which these portable engines were hailed in the mining districts of Peru in South America, where, from the mountainous state of the country, the badness of roads and scarcity of water, every attempt to introduce other steam engines had failed, will be found related in a short, but interesting letter, in the 1st volume of the Transactions of the Royal Geological Society of Cornwall.

The general external appearance of Mr. Trevethic's engine in its complete state for working in a fixed position is shewn at Fig. 137, Plate XIII. When applied to loco-motive purposes the construction is the same, except that it is mounted on four wheels, one of which is the fly-wheel shewn in the Figure. The boiler of this engine is perhaps one of the best that can be conceived for the economy of fuel, though unfortunately it will not admit of great extension of size without in some measure diminishing its security. It consists of a cast iron pipe or cylinder *p r*, which is seldom more than 3 or 4 feet in diameter, and from 9 to 12 feet long, according to the size of the engine, or it may be made much less.

When large it must of course be formed of several rings or pieces firmly bolted together, and caulked with iron cement,* so as to be perfectly air and steam-tight. The end next *y* is cast solid or close, but the other is closed by the circular plate or front *r*, the whole boiler being supported by the four legs or standards *s s t t*, upon a block of brickwork or masonry built to support it. The fire is made in a wrought iron tube in the form of a syphon, the two legs of which lie horizontally within the large cylinder *y r*, and this syphon is attached at its two ends to the front plate *r*; at one end it is so large as to embrace the fire door and ash pit *v*, together with the bars upon which the fire is made within the door, but its other end contracts into the iron flue or chimney pipe *w w*, which must rise high enough to create sufficient draft for the fire. The large cylinder is filled with water above the surface of the syphon fire-pipe, and *x x* are gauge cocks placed at different heights to ascertain its contents. All heat therefore that radiates from the fire, and even from the hot cinders below it, must be communicated to the water, while the steam produced is retained in the upper part of the large cylinder. A safety valve is placed at *z*, and *a b* is a mercurial syphon gauge with its floating stick, as before described, or with a string passing over a pulley and a counterpoise weight, because the gauge in this case must be 60 or 70 inches long on account of the steam being sometimes required to press with so many pounds upon each square inch. Every part of the steam or working cylinder is hidden in this engine except its top *c*, because the whole cylinder is immersed in the hot water and steam, being fixed by a flanch at *c* while its lower part extends nearly to the bottom of the boiler. In this way the cylinder is most effectually kept at the same heat as the boiling water: *e* is the piston rod, which instead of being attached to a beam, carries the T piece *f f*, which moves between the guides, or steadying bars *g g*: *h h* is the fly-wheel, the shaft or axle *i* of which passes through proper brass bearings in the two legs or supports *t t* while each of its ends carries a crank *k* (one only of which can be seen in the Figure) connected to the T piece by the two connecting rods *l l*. As the piston moves up and down, rotory motion is communicated to the fly-wheel, and from its shaft to any machinery requiring such motion; but when vertical reciprocating motion is necessary (as in pumping) it is obtained from the T piece. On account of the force of steam required in these machines, no feed pipe can be applied to supply the boiler, without making it of a very inconvenient height; water is therefore supplied to the boiler by a small forcing pump *m*, worked by a lever connected with one of the connecting rods *l*, and this water instead of passing immediately into the boiler is delivered into a pipe or receptacle *n* fixed upon it, and opening into it by the pipe *o*, so that the cold water by traversing the full length of this pipe becomes considerably heated, and does not check the production of steam.

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* Iron cement is formed of the borings of cast iron guns or turnings of cast iron which should be clean and free from rust until used. By slight pounding or trituration they are broken but not powdered, and then coarsely sifted. At the time of using, they are to be mixed with powdered sal ammoniac and sulphur, and slightly moistened with water; when the composition must be rammed or caulked into the joints with a blunt caulking chissel and hammer, and the joint must be then screwed up by its bolts as tightly as possible. No more of this cement must be made than can be used at one time, because it soon spoils; but if good, will become as hard as the iron itself in a few days; 2 oz. of sal ammon. (mur. ammon.) and 1 oz. of sulphur is sufficient for 5 lbs. of iron borings. For some purposes 1lb. of grindstone dust to the above, improves the composition. This cement is only applied to joints that do not require to be afterwards opened. Those that do are generally made with flannel and white lead ground in oil, or what is called *Gaskit*, which is a number of loosely spun hemp yarns plaited together in a flat plait, of a size depending on the size of the joint. This when applied is well anointed with white lead, mixed with a sufficient quantity of red lead to act as a dryer. The joints of the lids of steam cylinders are made in this manner.

In these engines the steam is admitted and released from the cylinder by a four-way cock such as has been described. This is placed just within the boiler at the top of the cylinder, and its lever is struck at the proper periods by tappets fixed on a small rod or plug-tree P, which is attached to, and moves with the T piece; and as a throttle valve is interposed between this cock and the boiler, the speed of the piston can be regulated with the same facility and certainty as in any other engine. The difference in action between this and the condensing engine, arises from the steam being much more powerful, and in its acting against the pressure of the atmosphere instead of against a vacuum; for no condensation takes place in this machine, not could it indeed be effected with sufficient rapidity on account of the great additional heat of high pressure steam. As soon therefore as the steam has performed its office of operating on the piston, it is by a motion of the four-way cock permitted to escape into the open air, while the newly admitted steam is operating on the contrary side of the piston. In passing to the open air it is generally conducted through a pipe in the inside of the cold water pipe *n o* in order that it may assist in heating the water before it enters the boiler.

From the above description it will be seen, that the high pressure steam engine is a much more simple compact and cheap machine, than the condensing one in which steam of less power is used in conjunction with a vacuum; and the only solid argument against its general introduction and use is the danger attendant on the explosion of its boiler, which when it does occur is accompanied by the most fatal and dreadful consequences. Still however there can be no doubt, but in time, proper materials will be selected, and such modes of construction adopted as will make the use of strong steam as certain as that of less power; and since it has been most clearly proved that the increments of power in the steam are greater than those in the fuel to produce that power, so of course the expence of working such engines must be proportionably lower. When accidents have occurred to boilers they may in almost all cases be traced, either to bad workmanship or materials, or an injudicious choice, application, union, or form of them. Thus those who are acquainted with the nature of foundry work, well know that it is next to impossible to cast a very large hollow vessel in one piece, with the assurance of its being equally thick, strong, and compact in every part; yet attempts of this kind have been made, and have failed; though smaller vessels properly formed might have been implicitly trusted. A flat surface is one of the worst for withstanding great force, yet such was the form of the cast iron that was applied to the end of the wrought iron cylindrical boiler of the Norwich steam boat, and which no doubt led to the accident before mentioned. But a cylindrical vessel with semi-spherical ends, or a globe, will withstand great force. It is on this account that Trevethic's engines are recommended not to be attempted on too large a scale, because while the power of the steam remains the same, the surface of the boiler increases as the squares of its dimensions. Thus if a boiler 2 feet in diameter and 3 feet long exposes 3000 inches of surface, and contains steam of an expansive force of 40 lbs. on the inch, the total force to burst the boiler will be 120,000lbs. If the steam be still supposed the same in power, but that it is acting in a boiler of twice the length and breadth, its force will be increased to 480,000lbs. because the surface will be four times increased, while from the greater dimensions of the parts they will be less capable of supporting and assisting each other. High pressure boilers, if large, should therefore be composed of small parts, effectually and scientifically united; and materials of the greatest tenacity should be selected, such as thick plates of hammered iron or copper, which, if they fail, will merely rend or open, while cast iron from its brittleness is dispersed in all directions by its bursting. Due attention should also be paid to placing such materials together as will expand and contract equally under equal temperatures, for the perfection and durability of a joint is greatly dependent on this circumstance. And no boiler of any description should be trusted until it has been proved by injecting cold water into it, by a forcing pump in the manner of Bramah's press (page 146) to be capable of withstanding at least twice if not thrice the force of the steam that is proposed to be generated within it, and which may be ascertained either by loading its safety valve, or using the mercurial gauge.

The high pressure engine of Trevethic was the only one that was used for a considerable time, but in 1804 a patent was obtained by Mr. Arthur Woolf, an ingenious engineer of Cornwall, for a new machine, which he did not however bring to perfection until 1810, when the improvements and alterations he had made in it were so great, that he was obliged to solicit a new patent. The perfection of this engine, as described by Mr. Woolf, does not however arise so much from any improvement in its construction, as from a new property which he states he had discovered in steam, and by which he was enabled to apply it in a new manner. His engine is in fact precisely that of Hornblower (Fig. 136, and page 320) with such slight alterations as to render it unnecessary to give a separate figure of it; and although this machine was non-effective when used with moderate steam, and especially during the continuance of Messrs. Watt and

Boulton's patent which precluded the use of their mode of condensation; yet it has since become of great importance, in the hands of Mr. Woolf. It has before been stated (page 313) that Messrs. Watt and Boulton's last improvement arose from their discovery of the elasticity of steam and its consequent capability of expanding itself, so as to act in a cylinder not quite filled with it. Mr. Woolf carried this principle much further, and claims a discovery which he endeavours to establish by proof, that whatever number of pounds steam might be capable of overcoming on the square inch, so many times would it expand, and yet remain equal to atmospheric pressure, provided its original temperature was maintained. In other words, if steam is strong enough to raise the mercurial gauge of a boiler 6 inches or to open an inch safety valve loaded with 6lbs. weight, against the pressure of the atmosphere; that same steam may be admitted into another vessel, six times as large as the first, and still it will be equal to steam of one atmosphere (or 212 degrees) so long as its first heat is preserved. Taking it for granted that this law holds good in steam, its beneficial action in a double cylinder will be immediately apparent, and such is *The Steam Engine of Mr. Woolf.* He proposod using steam of about 40lbs. power on the inch, and this was to be admitted by the pipe *c* Fig. 136, Plate XIII. into the cylinder *a b* precisely as before described in speaking of Hornblower's engine which was only altered for his purpose by making the second cylinder much larger than the first. For if steam of 40lbs. was capable of extending its magnitude forty times, and yet remained equal to the atmosphere, of course, if the second cylinder had forty times the capacity of the first, the steam when discharged into it would still be atmospheric steam. A condensing engine however requires steam of about four pounds more than atmospheric power on the inch;

consequently, if the second cylinder be not quite forty times the size of the first the entire object will be gained; for the steam on its first admission will act with a power of 40lbs. upon the first piston *n* to raise it, and is afterwards admitted to act above the second piston *o* to depress it into the vacuum formed in *h* by the ordinary process of condensation; while at the same time a new quantity of 40lbs. steam has been let in above the first piston *n* to assist in the operation. This engine therefore consists of a high pressure and a condensing engine so united, as to act with one common quantity of steam, which is made to co-operate on two pistons always moving in the same direction at the same time, and thus uniting their power.

The beam, fly-wheel, hand geer, and various other parts of an engine as before described are applied in this, as in all other steam engines, consequently nothing need be said upon them. But Mr. Woolf was too well acquainted with the nature of strong steam to attempt its production in any of the large boilers that are commonly used for this purpose, and he therefore invented a boiler peculiar to himself, and which formed part of his patent invention. In this, which is altogether made of cast iron, he very properly uses forms which admit of the greatest strength in their construction while none of the parts individually expose much surface to the action of the steam. His boiler consists of several strong tubes of about 10 inches in diameter and the entire length of the fire place. They are placed parallel to each other in a gently sloping direction, at a small distance above the fire, and their upper ends all open into the lower side of a large cylinder set above them in brickwork in such manner that its lower part is also exposed to the fire. Some idea may be formed of this arrangement by Fig. 138, which is a perspective view of the iron vessels of one of these boilers, without the brickwork in which they are set and supported; *a a a* are the sloping tubes, placed immediately above *b b* the fire bars, and *c c* is the large cylinder into which the lower tubes enter. This large cylinder is about half filled with water, which of course runs down into all the tubes, and in these, as well as in the upper cylinder is the water boiled: *d* is the man-hole for cleaning or examining the boiler, *e* the steam pipe for conveying the steam to the cylinders, and *f* the loaded safety valve. The steam as it is generated in the lower tubes rises up into the large cylinder through the water contained in it, and is retained above it until required by the engine. In closing the lower ends of these tubes, and in joining them to the large cylinder, as well as in various other parts of the engine, Mr. Woolf makes use of a kind of dove-tail joint without screw bolts, which is very simple, cheap, and efficacious against high pressure steam, for it is so constructed that when once the parts are put together, it is impossible they can separate again without a previous fracture. The method Mr. Woolf took to insure the due temperature of the steam in his cylinders was that of making their jackets or casings the passages by which steam was delivered into them, for it passed from the boiler into the casing, and from thence to the interior of the cylinders, which were thus kept at all times, as hot as the steam that had to enter them. On the whole therefore it will be seen that no pains have been spared by its ingenious projector to make this engine as perfect and as safe as is consistent with the nature of high pressure steam. The accordance stated by Mr. Woolf to have been discovered by him between the exact power of steam and its expansion, was considered by all, as of an extraordinary nature; but more recent and accurate experiments that have been tried, show that it does not exist to the extent at first imagined: consequently the disparity in size between the two cylinders is found to be much less than was at first hoped and expected. The large cylinder is however made from 5 to 6 times the size of the smaller one, and in this proportion the engine of Woolf appears to be the most powerful, with the least consumption of coal of any that has yet been laid before the public. It has been chiefly used in the mining districts of Cornwall, where perhaps a better opportunity of examining its merits has occurred than could be met with in any other place, not only from the great depths of the mines, and the nature of engines being there so well understood and so often put in competition with each other, but from the intrepid manner in which high steam is there regarded; for had it been liable to accidents, they must have frequently occurred.

Notwithstanding the arguments that may be adduced in favour of high pressure steam engines, still the author cannot help expressing his opinion that they should in no case be resorted to, where the low pressure or condensing engine can be substituted in their stead. The saving of a small quantity of fuel may in many cases be an object of great importance; but where this is not actually the case, it is by no means to be put into competition with the lives of the workmen who may be constantly surrounding the machine, and who therefore cannot ever be exempt from some risk of danger. It is true that accidents do not very frequently occur; and it may be urged that the low pressure boiler being constructed in a weaker manner, is more liable to accidents from inattention to the fire, than that which is constructed with a direct view to strength. How far this is the case, after the description that has been given of the low pressure boiler need not be urged. But admitting that the one is as secure as the other, still the effect of the explosion is sufficient to turn the scale of preference, for while the bursting of a low pressure boiler hardly ever extends its influence beyond the limits of the room which contains it; that of the high pressure spreads devastation around it on all sides; of which unfortunately there are but too many instances on record. It is however daily gaining ground, and with further and better experience may at length become safe and common; but in its present infant state, surely it should be kept away from population, and only be resorted to as matter of necessity, where its failure cannot be productive of much mischief. In America the use of high pressure steam has been much more common than it has yet become in England, and there it is by no means a rare occurrence to hear of the use of steam equal to 100lbs. or more on the square inch.

Before dismissing the subject of the steam engine it will be necessary to offer a few remarks on the attempts that have been made to improve it, by dismissing the beam, and obtained a circular or rotory motion immediately from the action of the steam without the intervention of a crank. Such a construction is unquestionably a great desideratum in mechanics; because the inertia of the heavy beam and piston, as well as the friction produced by them and their appendages must be overcome at every stroke, and not only abstract greatly from the power of the machine, but add to the expence of its construction. All the attempts that have hitherto been made to accomplish this desirable end, have however so far proved ineffectual; at least they have been attended with such practical difficulties as to have precluded their general introduction into practice; for the friction attendant upon them, as well as the difficulty of maintaining the packing in a steam-tight condition has proved so great as to more than overbalance every expected advantage. Indeed the difficulties attendant upon this construction of engine are such as to leave little hope of its ever being brought to that state of perfection which may render it superior, or even equal to the engine in its alternating form.

Most of the engines that have been proposed on this construction, consist of vanes or sails of metal attached to a central shaft or arbor made to revolve in the interior of a truly bored cylinder or drum, in the same manner as in the pump shewn at Fig. 102, Plate IX. In that example, if steam was admitted in a contrary direction to that in which the water flows, or at the upper pipe *f*, it would enter the cylinder *a d*, and cause the central drum *b* to revolve until it had an opportunity of escaping by the lower pipe *e*; and before this could take place another vane would be in a situation to receive the steam, thus producing continuous motion without condensation, and consequently constituting a high pressure engine. Very nearly the same principle with slight modifications is sometimes used to produce a vacuum by condensation on one side of the vane, while the steam is acting on its opposite side, thus producing a low pressure or condensing engine. But the great practical difficulty in these engines, (for they all approximate more or less to the example that has been given,) is keeping the packing free from wear as it passes the orifices of the pipes leading into and out of the cylinder, and likewise in packing the sides of the vanes so as to keep them steam-tight without such inordinate friction as may prevent their due action. Mr. Watt, Mr. Hornblower, and several others, after having made many attempts, which proved ineffectual, towards perfecting this engine were under the necessity of abandoning the project, after it had been put in many forms without avail. Another method of producing immediate rotary motion from steam, is that of constructing a very large hollow wheel with a hollow axis and arms for the passage of the steam. The steam is admitted at one end of the axis, passes up one of the arms, and thus gets into the hollow rim or periphery, which was directed to be about half filled with quicksilver, or the metallic alloy that fuses with a less heat than boiling water,* by the first patentee, Mr. Onions of Bristol: while in the more recent patent of Mr. Masterman, it is proposed to use common water for the same purpose. The periphery of the wheel has two valves within it at opposite sides, but opening in the same direction, and the steam by being admitted between a valve and the fluid, causes that fluid to rise and pass through the next valve so as to make one side of the wheel heavier than the other; consequently, it moves partly round, by which the cocks or valves for regulating the direction of the steam are moved and varied, and the steam already in the wheel, is permitted to escape through another of the arms, and the end of the hollow axis opposite to that by which it had been admitted, while a new quantity of steam is at the same time admitted into the other half of the periphery to maintain the elevation of the fluid. Mr. Onions discovered a curious fact in the use of the fusible alloy in this machine, viz. that, like water, it increased in dimensions by cooling and crystallizing when it became solid. Unless therefore the metal was kept hot, or removed while in a fluid state, it burst open the pipes in which it was contained. The engine of Mr. Mastermann is described at full length in the Repertory of Arts, Vol. XLI. page 139, Second Series, and is so nearly allied to that of Mr. Onions that a separate account of it in this place was deemed unnecessary. Many other contrivances for producing rotary motion might be named; thus Mr. Sadler attempted to obtain it by causing steam, instead of water, to issue from a Barker's mill (page 226), Mr. Donkin and Sir William Congreve, by throwing steam into the buckets of an inverted overshot wheel moving in a hot fluid; but as none of these contrivances have yet been received into general practice, or adopted in manufacturing concerns, it may be inferred that they have not answered so well as the engines that are in daily use, and on this account it was thought unnecessary to enter more largely into their descriptions or to illustrate their constructions by figures. Notwithstanding the length to which the foregoing account of the steam engine has been extended it gives but a very slight and imperfect idea of the almost endless ingenuity and contrivance that has been expended upon this most valuable machine. A machine to which the manufacturing and mining interests of Great Britain must ever confess their obligations. Its importance is the best and only apology that can be offered for the space that has been allotted to it in the present place, and long as the account may appear, yet it does not profess to describe or even enumerate any thing like a catalogue of the various transformations and improvements which the steam engine has undergone, but merely to state the leading features of its best and most approved constructions, as they have from time to time arisen; and it is hoped and believed that none of these that are at all important have been passed over in silence. It therefore now only remains to offer a few observations on the power of the steam engine, and the manner in which it is calculated or estimated.

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* Fusible metal is composed of 8 parts by weight of bismuth, 5 of lead, 3 of tin, and 1 of quicksilver. Spoons cast of this metal will melt in a cup of very hot tea. It may also be fused over a candle on writing paper without burning it.

From the foregoing description it will be evident that the power with which an engine moves must depend upon the force of the steam, and the area or superficial contents of the piston upon which it is permitted to act; so that by calculating the number of square inches in the piston, and knowing the power with which the steam presses on every square inch of the boiler, (either by the steam gauge or other contrivance,) the result appears very simple; because we have merely to multiply the area of the piston in inches by the force of the steam in pounds, ounces, or other denominations of weight, and the result will be the force with which the piston should move, expressed in the same denomination. If therefore the piston of a single acting engine (page 279) be 54 inches diameter, as in the water works concerns beforementioned (page 281), such piston will contain very nearly 2291 square inches of surface, and if the barometer of the condenser (page 310) indicates that the air pump is maintaining a good vacuum within it, and the steam gauge of the boiler stands at 2 inches, or shows that the steam is equal to two pounds on the inch, while the household or weather barometer (page 105), stands at 30 inches; then the force acting on such a piston to depress it, and raise the pump will be 38,945lbs. or rather more than 17½ tons; for if the vacuum was perfect, it would permit atmospheric pressure alone to operate at the rate of 15lbs. on every inch when the baromer was at 30 inches, and as the steam is two pounds to the inch more powerful than the atmosphere, so of course there would be a pressure of 17lbs. on every square inch of the piston which would produce the above result. This enormous force is no doubt called into action, but notwithstanding this is the case, yet from the little steam that remains uncondensed in the pipes, the unavoidable imperfections, even of the best workmanship, and the friction and inertia of a complete steam engine, it is found that the actual quantity of disposable power, or that which is left by the engine to drive other machinery, after producing its own motion, cannot fairly be averaged at more than about 7lbs.

on each inch of the piston. In large machines the friction is less in proportion than in smaller ones, and consequently a greater allowance may be made, particularly when the weather barometer stands above 30 inches, which is seldom the case for long together. A small engine on the contrary requires a greater allowance, and therefore in taking the average size of condensing engines, together with the average height of the barometer, state of the air pump, and strength of steam used with them, from 7 to 7½lbs. is as much as can fairly be considered as the disposable operative force upon their pistons; and consequently out of the 38,945lbs. of power operating on the piston above named, no more than 16,036lbs. or thereabouts can be considered as acting on the pumps. Some engineers allow half the actual power to remain as disposable force; but at all events, half the actual power must be considered as lost or absorbed in friction, resistance, &c. and hence it appears how very desirable it is to strip the engine of its beam, crank, fly-wheel, air and cold water pumps, and in fact, every thing that can produce friction, resistance or inertia, and upon this are the chief hopes of those who have laboured to produce good rotary engines grounded. The high pressure engine likewise derives some of its best properties from this circumstance, for independent of its greater simplicity, its friction is diminished by all its working parts being smaller; and even if this were not the case it would bear a less proportion to the power of its steam. If a condensing engine working at 14lbs. to the inch looses 7lbs. nearly half the power of the steam is wasted; but if that same engine was worked by steam of 40lbs. the friction would still remain the same and would amount to little more than a sixth part of the power of the steam.

In this way by consulting the barometer and the steam gauge, may the force acting on any piston be determined;

or the reverse of the proposition, for if the amount of any load be known (the power necessary to work a pump, for example) there can be no difficulty in calculating the size of a piston that shall overcome it with any given power of steam. But from what has before been said on the nature of power (page 40, &c.) it follows that before we can come to any comparative statement of the power of a steam engine so as to obtain definite ideas of what it can perform, we must consult the velocity of its motion as well as its force. Steam engines on their first introduction were very frequently used as substitutes for horse mills which had preceded them, and hence if a mill had been worked by two or more horses it became necessary to construct the engine in such manner that it should be equal to the work of so many horses; for if rendered more powerful than necessary, a waste of fuel must ensue, while on the contrary if not powerful enough, the work would not proceed in a satisfactory manner. It therefore became customary to designate engines by *horses power*, a custom, than which, nothing can be more vague and unsatisfactory, though continued in some few instances to the present day. The best mechanics are by no means agreed as to what the actual power of a horse is, or should be called, nor is it likely that such an agreement can take place, when it must be dependent on the age, size, health, and vigour of the animal, as well as on the food, climate, and position in which he works. Nothing more than a rough average can therefore be taken, and this is by no means to be put into competition with the certain results that are always obtained from perfect machinery. Mr. Smeaton, whose accurate investigations and extensive practice as an engineer none can doubt, makes the average power of a horse equivalent to raising 22,916lbs. 1 foot high in a minute, and states that he can continue this work for 8 hours in a day. Dr. Desaguliers on the contrary allows 27,500lbs. while Messrs. Watt and Boulton extend the allowance to 32,000 avoirdupoise. For an engine to be equal to the power of a horse, it must therefore not only raise this same load, but must move it with the same velocity, for power and velocity can never be separated in the investigation. By moving the load we are to understand moving it by the piston, and consequently if the piston rod of an engine rises or moves 1 foot in a minute with a weight of 32,000lbs. upon it, the engine to which it belongs must, according to Watt and Boulton's estimate, be a one horse engine. No steam engine however moves at this slow rate, but from numberless experiments that have been made, it is found that from 200 to 220 feet in a minute is the best speed for a piston to travel; hence small engines work much more rapidly than large ones; for if the cylinder of a double engine is so small as only to admit of a 2 feet stroke, its piston must ascend and descend 50 times in a minute to pass through 200 feet, while an engine having a 10 feet stroke will make but 20 alternations in the same time, or move upwards and downwards 10 times. Now since the one-horse engine beforementioned, would pass through 200 feet instead of one foot in the minute, it need only carry one two-hundredth part of its former load, or 160lbs. to give it the same power; for 160lbs. moved 200 feet in a minute is the same thing as 32,000lbs. moved one foot in the same time. If therefore we can ascertain the weight that any engine lifts, and the distance to which it carries it in any given space of time, it becomes easy from such data to determine how many pounds avoirdupoise are raised one foot high in a minute, and dividing this by Watt and Boulton's denomination of power as before given, or any other that may be adopted, to ascertain its value in horses power.

Speaking of engines in horses power certainly conveys more definite ideas to the mind, than stating that they can raise certain weights to certain heights in certain times; but at the same time it is much less mechanical, and much less used now than formerly. For since the horse has no connection with the engine, and the employer of it, to do justice to himself must investigate the subject in a pecuniary, rather than a mechanical point of view; so the only real and beneficial comparison that can be made, is between the work done, and the money expended to perform that work; and since that money is principally expended in coals or other fuel which varies in price in different countries, so the manner in which the power of engines is now generally computed is by a comparison of the work done with the quantity of coals consumed to effect that work; and in this manner of treating it, every man, whether possessing mechanical skill or not, can judge for himself. He knows by experience that the performance of a certain portion of labour will require a certain number of men and horses, and he knows what the maintenance of the first, and the purchase, and maintenance of the latter will amount to: and being told that an engine of a certain price and magnitude will do the same thing with a certain quantity of coals, the price of which he is also of course acquainted with in his own district, he is at once able to weigh the comparative profits and disadvantages of the two modes of proceeding. By this mode of computation, time is likewise disregarded, for Messrs. Watt and Boulton say that 48lbs. or one bushel of Newcastle coals used without waste under one of their double condensing engines will raise 30 millions of pounds one foot high, without stating in what time, or with what power of engine; because a bushel of coals should last twice as long under a 10 horse, as under a 20 horse engine, or rather the two engines should do the same quantity of work with the same quantity of fuel. One bushel of coals they consider likewise as equivalent to the grinding and dressing of 11 bushels of wheat; but a double condensing engine lately made and put up by Mr. Penn, millwright of Greenwich, for Mr. Ritchie of the same place exceeded this quantity, and ground and dressed 400 bushels with 36 bushels of coals. The cylinder of this engine is 24 inches diameter, with a 5 feet double stroke which it repeats 22 times in a minute, so that the piston travels 220 feet in this time, with steam of 4lbs. and this shows it to be what is generally denominated a 20 horse engine. If the air pumps of steam engines could produce perfect vacuums in their condensers, the full power of the steam would be permitted to act; but since this perfection is not attainable, even in the small and accurate air pumps used for Pneumatic experiments, of course it cannot be expected in a large machine. This accounts for a great part of the apparent loss of power before stated, because although steam of 2lbs. above atmospheric pressure should press at the rate of 17lbs. on every inch of the piston when the barometer stands at 30 inches, yet it can only do so when a perfect vacuum exists on the opposite side of the piston, which never is the case; instead therefore of the vacuum assisting the steam to the extent of 15lbs. as it has been presumed to do, its general average cannot be considered as more than 10 or 12lbs. at the utmost. When an engine is in good order and has light work to do, it frequently happens that it will work with steam of less power than the atmosphere. If for instance the steam should be 2lbs. under the pressure of the atmosphere when the engine is making a vacuum equivalent to 12lbs.; that steam will still act on the piston at the rate of 10lbs. on the inch, which may be sufficient to drive the engine, and in this case from the boiler being partly exhausted, the atmosphere will press upon it externally, and has been known to crush it inwards. Such an accident is provided against by fixing a small spring valve in the top of the boiler so as to open inwards, and admit air, to restore the equilibrium, whenever it may be necessary.

With respect to the quantity of coals consumed by engines when computed according to horse power, one bushel is the allowance usually made for each horse power for a day's work; but the day when spoken of, as applying to horse's work is but 8 hours of actual labour. This allowance has by many been considered as insufficient, and for small engines it is perhaps not quite ample. But the author had an opportunity of investigating this subject very accurately in the engine before alluded to at the York Buildings Water Works, Villiers's-street, Strand, which was erected a few years back by Watt and Boulton, in their best style. The experiment was tried for a whole year, during which time the coals were measured out, and the consumption ascertained to be 19,700 bushels, or rather better than 547 chaldrons. The engine by its size and performance was what would be called of 60 horses' power, and it worked every day except Sundays for an average of 8 hours. As there were 313 days in the year, deducting Sundays, so at the rate of 60 bushels a day, the total consumption should have been 18,780 bushels; the excess therefore amounted to no more than 920 bushels, which is amply accounted for; because notwithstanding the engine was at work but 8 hours in each day, yet the fire was never extinguished the whole time, but was kept burning as gently as possible during the nights and Sundays to maintain the heat of the boilers, and as a precaution, in case fires might happen in the district. There is no doubt therefore, but that if the engine had been constantly worked, one bushel per horse power for each 8 hours work would have been more than sufficient.

What may be effected by proper attention to the fire is rendered sufficiently evident by the revolution that has been brought about in the mining districts of Cornwall, through the appointment of an Inspector General of the engines there.* By an arrangement among the mine proprietors, Messrs. Thomas and John Lean, were some years ago appointed inspectors of all the steam engines in a very large district. In consequence of which a degree of emulation never before known was excited among the engine workers that was attended with the happiest results to their employers; for a much larger quantity of work was done, with a diminished quantity of fuel. Thus in the year 1811, when this inspection was established, the average of eight inspected engines was only 15,760,000lbs. of water raised one foot high with each bushel of coals. But such was the attention and desire of excelling among the engine-men when they found their proceedings watched over and reported upon, that in 1813 the average of 29 engines, including those already alluded to, and among which are none of the engines on Woolf's construction was increased to 20,162,000lbs. making a difference of nearly five millions of pounds of water to each bushel of coals, and this arising from no other cause than additional care and diligence!

The monthly reports of Messrs. Lean were all made from personal inspection, and verified on oath, after which they were printed and circulated; abstracts were also given of them in the Philosophical Magazines, after August 1815; and from the respectability of the parties, and the sanction they met with among the mining proprietors, no doubt can be entertained of their authenticity, more especially as their statements were undisputed. It is therefore from such investigations that the value of any particular construction of engine can be more fairly deduced, than from any other source; and it was these reports which proved the superiority of Woolf's engine as before noticed.* For after the most impartial examination for several years in succession they shewed that his engine at Wheal Abraham mine raised 44 millions of pounds with a bushel of coals, while the best condensing engine of Watt and Boulton at the Dalcoath mine did but 43 millions. This was again corroborated by the evidence of Messrs. Lean, delivered before a select Committee of the House of Commons in 1817, when it appeared that the average saving of fuel in favour of Woolf's construction was from two to three-fifths greater than that of any other engine.

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* For an account of this appointment, and a table of the coals consumed and work done by engines in Cornwall, see Philosoph. Mag. Vol. XLVI. page 116.

Such is the account of the Steam Engine as it at present exists, but what the future historian may have to state respecting it, time alone can develope. To attempt any thing like even an enumeration of the purposes to which it is applied, would be to give a catalogue of every art and manufacture in the world. In one place we find the miner employing it to drain the deepest chasms of the earth: while in another it sets the wind's uncertainty at defiance, and conveys our packets across the ocean with a precision that would have formerly been deemed chimerical. The bread we eat, the clothes we wear, the furniture we use, nay, even the printing of the books and newspapers we read, are alike the produce of its versatile power; and when we consider that so feeble a creature as man can construct and controul a single machine, equal to more than the power of a thousand horses the end.

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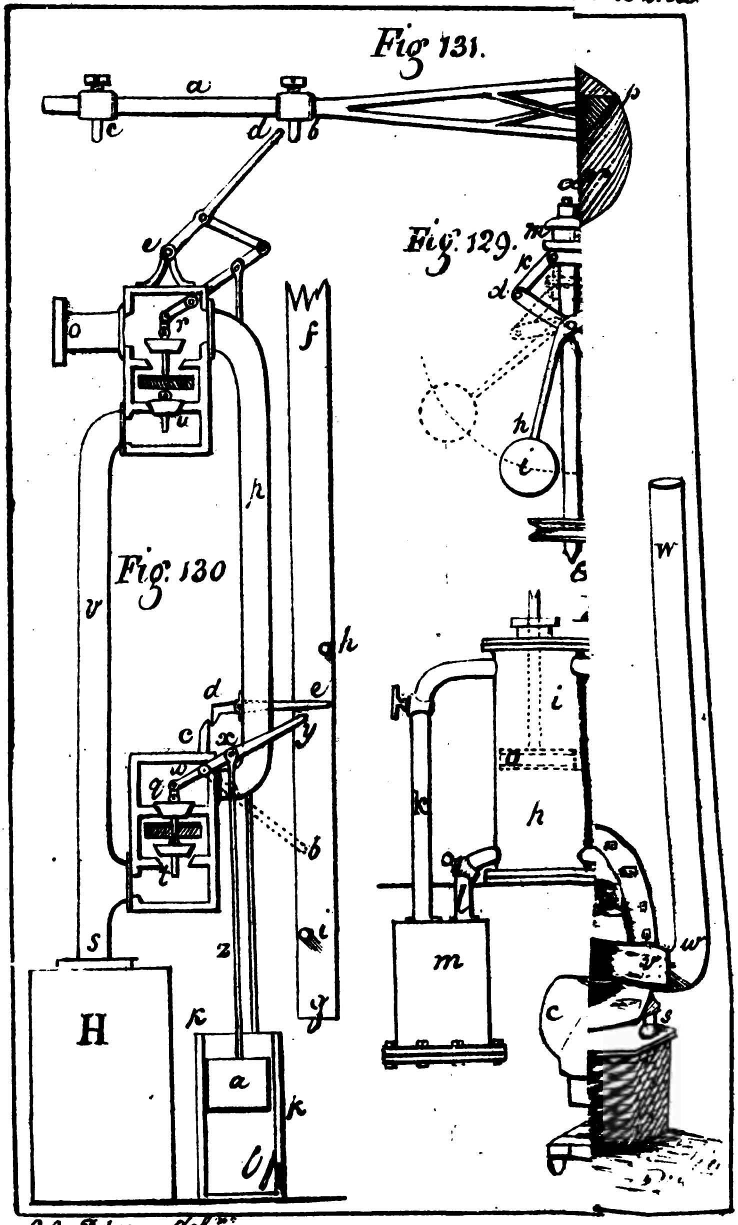
* For more minute particulars respecting the power and construction of Woolf's engine, see Phil. Mag. Vol. XIX. page 133. Vol. XXIII. pp. 123 and 335. and Vol. XLVI. pp. 43 and 120.



G. C. Dobson. del.

working at once, as at the Chasewater mine in Cornwall, and is alone enabled to do this by studying and investigating the simple laws and operations of nature, no one can consider that time misapplied, which is devoted to the pursuits of Natural Philosophy, even if this were a solitary instance of the advantage to be derived from it. Its powers are however much more exalted, for at the same time that it teaches us the best means of exerting our natural mechanical energies, it exalts the mind by obliging it to exercise the faculty of thinking, and enables us to form higher conceptions of the wisdom, power, and goodness of the Great Disposer of all things than can be derived from any other source.

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